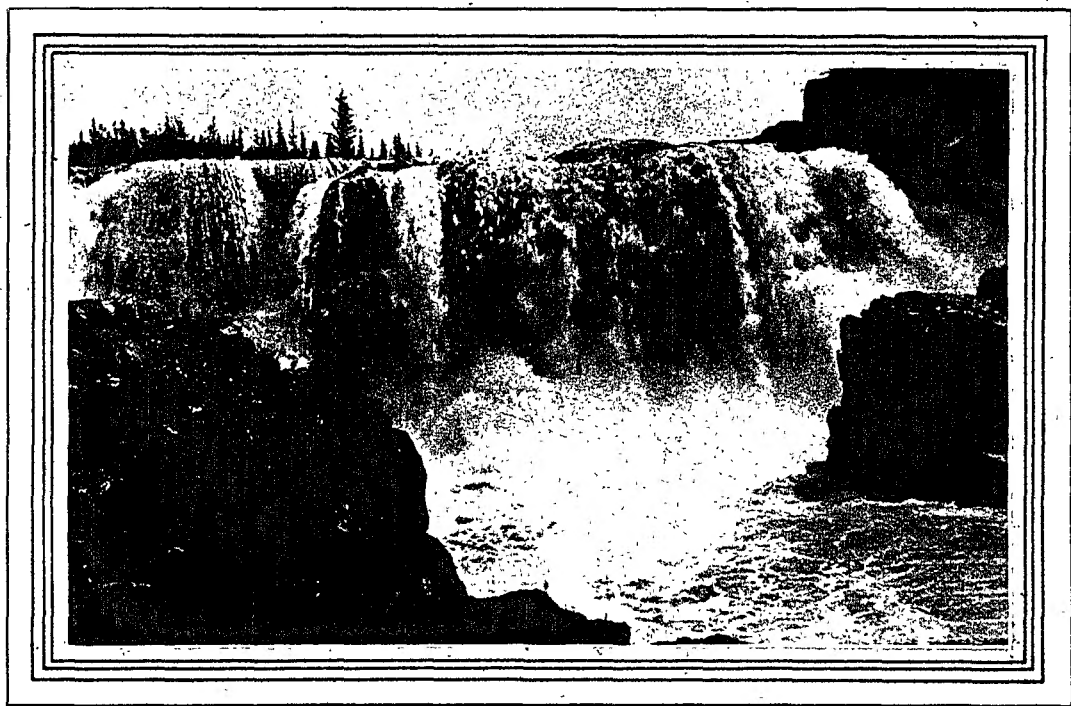


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The
WATER RESOURCES
of
MANITOBA



The Honourable John Bracken,
Premier of Manitoba.

Sir,

I have the honour to submit herewith a report on the Water Resources of Manitoba, being Project No.11 under the Economic Survey, and the 12th of a series of reports covering many phases of the economic and social life of the province. This report is the work of C.H.Attwood, Director of Water Power and Water Rights, Department of Natural Resources.

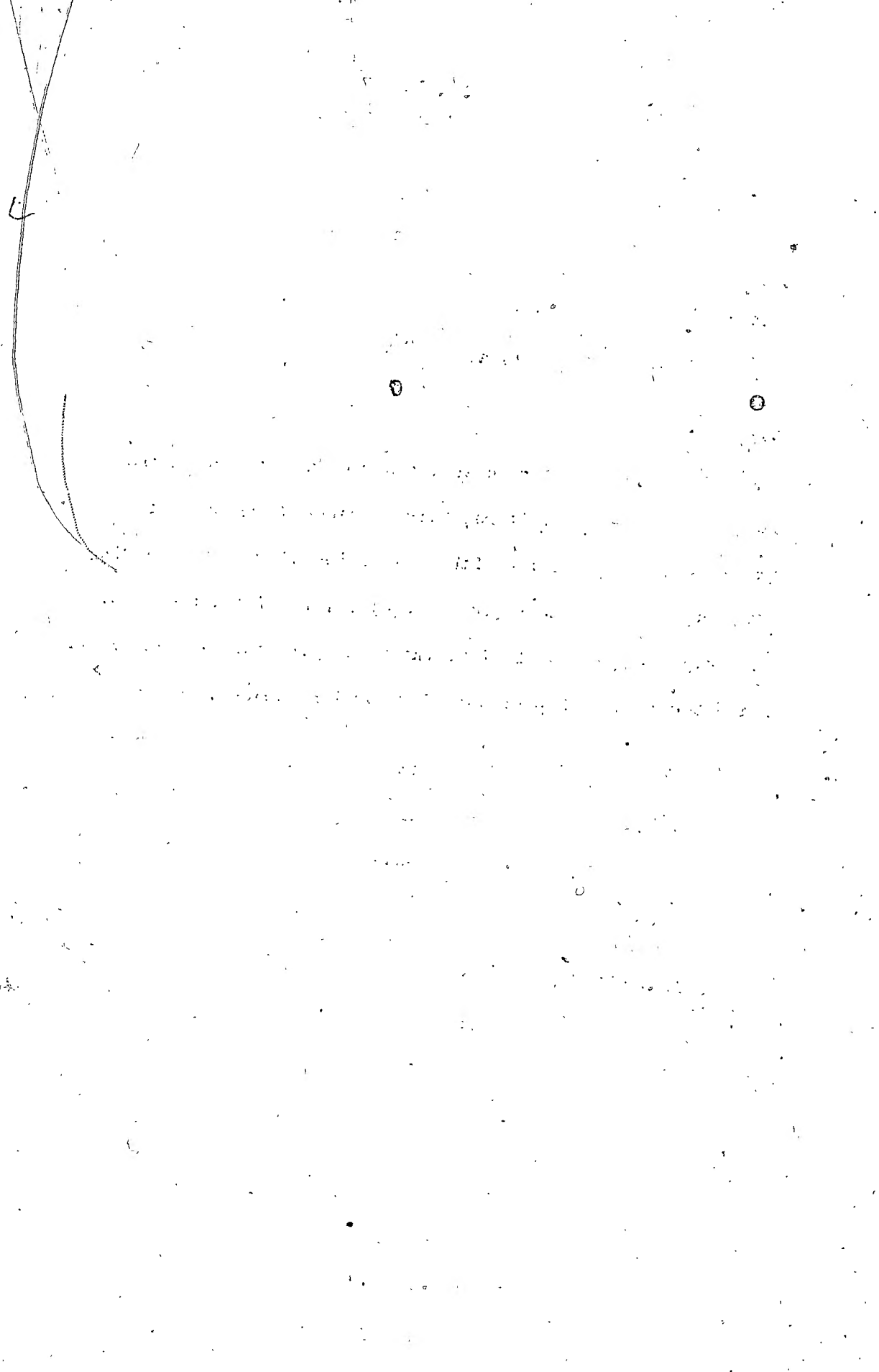
I have the honour to be,

Sir,

Your obedient servant,

C.B.Davidson,
Director.

Winnipeg, Manitoba,
June 15, 1938.



THE WATER RESOURCES OF MANITOBA

- by -

C.H.Attwood
Director of Water Power and Water Rights
Department of Natural Resources
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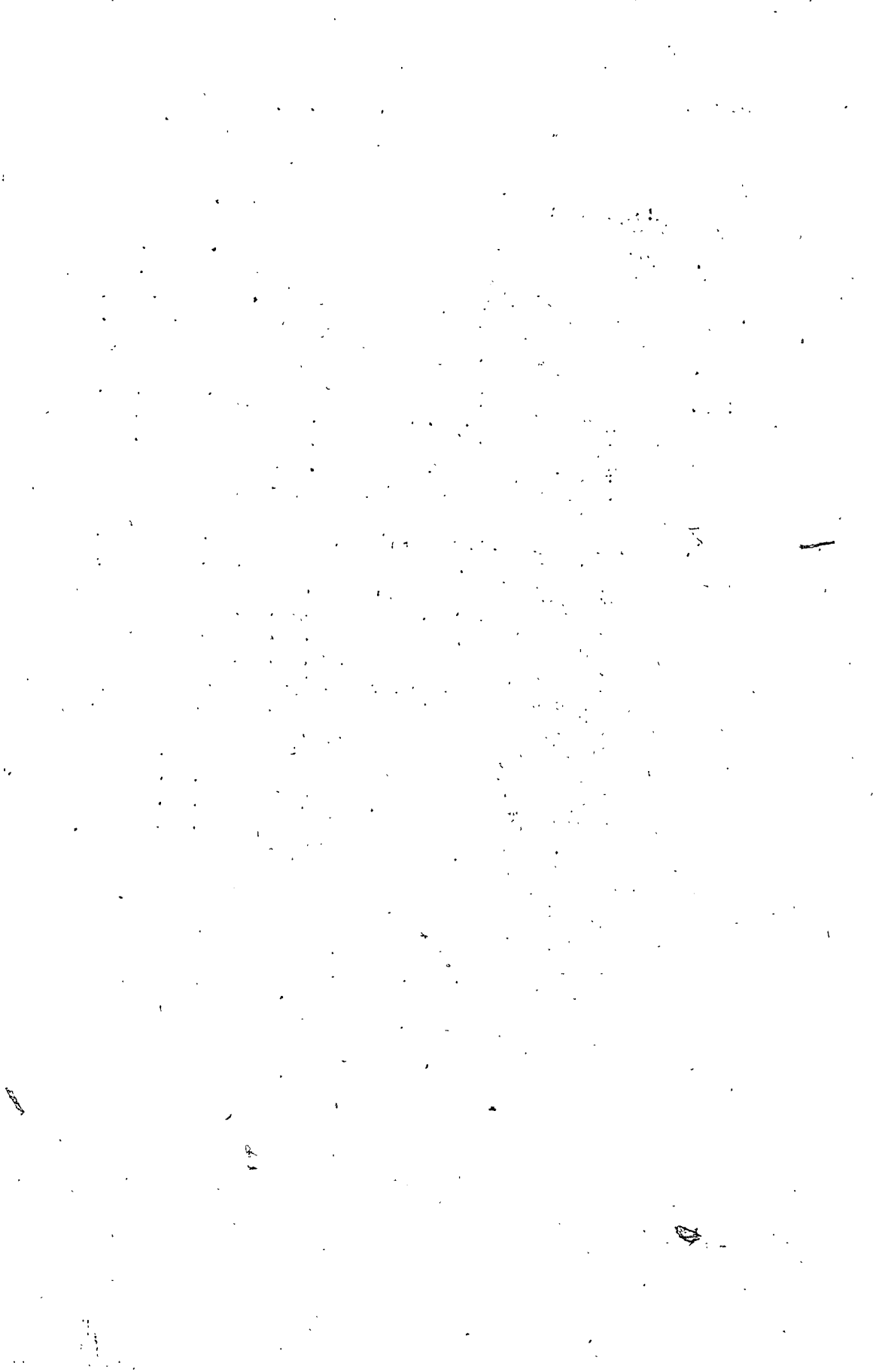
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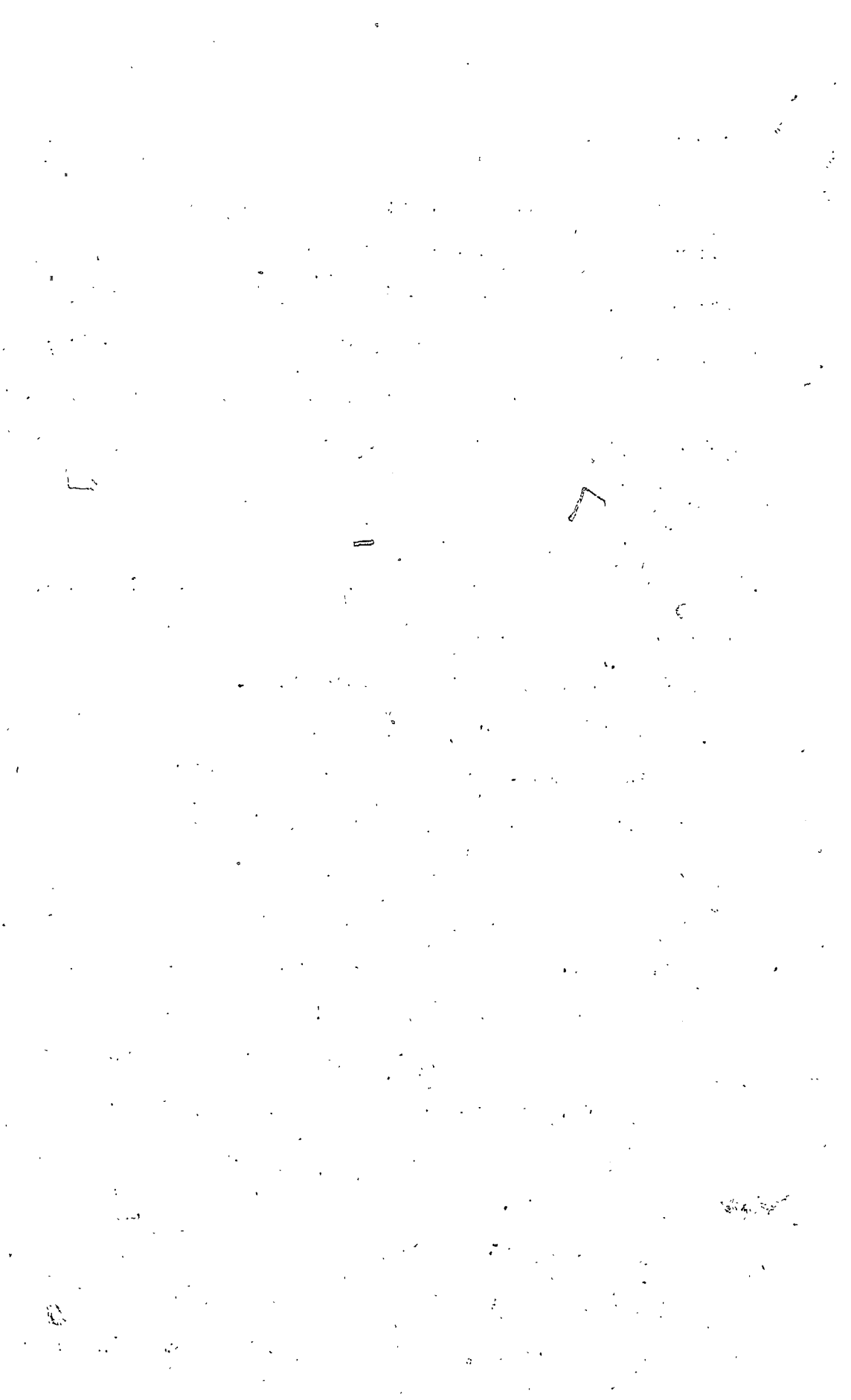


SUMMARY

In this report an attempt has been made to present a general view of the various problems relating to water, including its origin and distribution, its use and misuse, its relationship to human activities, and its effect on population. Briefly stated, water is the most essential of our resources in maintaining life of any kind upon this earth, and under properly planned programs of conservation and development it forms one of the most important factors in the progress of civilization.

Water, as we find it in the lakes, streams and oceans, and, in fact, distributed over the whole surface of the earth, is constantly being renewed by precipitation, in its various forms, and is transported from place to place in either surface or underground channels. Likewise, after it reaches the surface of the earth it is constantly being diminished in quantity by the various agencies of percolation, transpiration, evaporation and run-off, these several agencies having widely varying effects from time to time and from place to place. Consequently the amount of water present at any particular time in any particular place is an extremely variable quantity resulting from the interaction of a number of inconstant factors, which, although subject to direct measurement for any given instant of time, cannot be predicted beyond that instant with any degree of certainty.

As a result of this uncertainty of prediction, it has been found necessary in all planning for the conservation and development of water resources, to adopt a method that assumes that future



variations will follow the same general pattern as past variations. This method involves as its cardinal principle the systematic collection and compilation of all data pertaining to water for sufficient periods of time to cover the variations that are likely to occur. Among the more important of these data are records of precipitation, temperature, evaporation and run-off, and the longer the periods over which a knowledge of the variation of these phenomena has been obtained, the more accurately can the future variations be predicted.

The data presently available are for comparatively short periods and only pertain to limited portions of the province. The run-off records which are so essential to the proper planning of the most beneficial uses of water are with few exceptions most incomplete and the establishment of gauging stations and evaporation stations requires considerable extension if the problems relating to these uses are to be properly planned. Concurrent with the collection of the foregoing classes of data, a further prerequisite to the planning of conservation and development of the water resources is the topographical, geological and soil survey of each watershed to determine what can physically and economically be done to control and put water to use. Added to this is the further requirement that involves a knowledge of human needs, so that adequate planning may provide for the most beneficial use of the water resources to the advantage of the greatest number of people.

For the agricultural portions of the province the soil-water relationship is of vital importance and is a problem which should be jointly studied with the technical agriculturist before contemplated

development is authorized or projected.

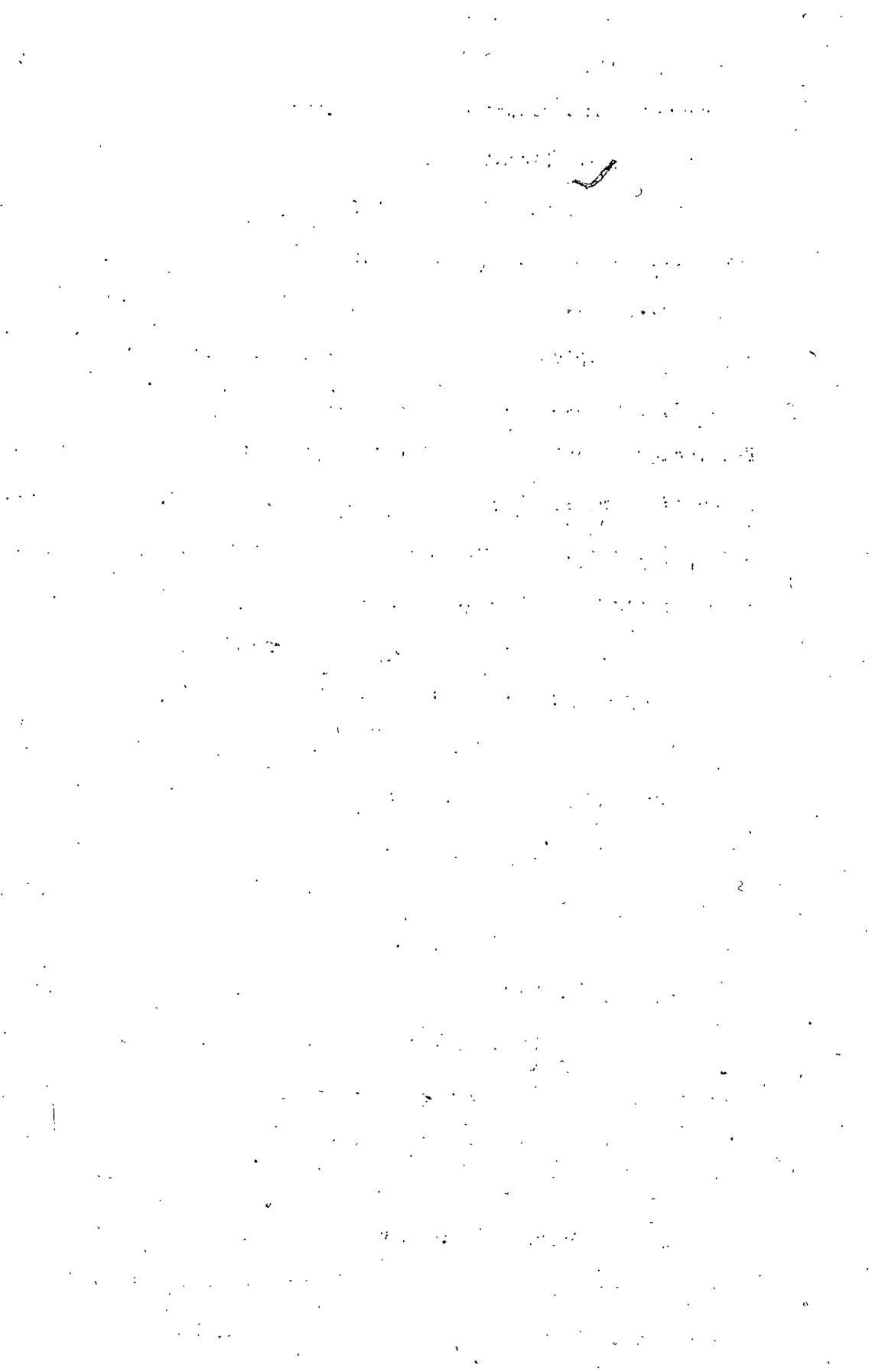
Every watershed is, in a sense, an organism. Each part has some intimate, vital relationship to every other part. The forests and grasses that control both run-off and erosion; the deeply eroded valleys and the alluvial flood plains and deltas; caved banks and mid-stream sand bars; the marshy reaches along the valleys, the restricted channel sections immediately below and the flood free valley below these; restricted sections where ice and debris jam to force the stream to seek or cut another channel around the obstruction, the higher velocities on the outside of the resulting bend cutting a still wider sweep, while silt banks form on the inside, the gradual sharpening of this ox-bow bend until ice and debris jam these to force the thwarted currents to erode a natural cut-off; all these and innumerable other factors have combined to determine the form of streams. By the interplay of these factors and forces through long ages of geologic time, nature may have achieved some form of balance. Each characteristic of any stream is both effect and cause. The erosion of a bank may form a sand bar which, in turn, reduces velocity and with it the rate of bank erosion and siltation. This intricate maze of cause and effect relationship, extending from the uppermost head waters to the final exit to the sea, accounts in part for the fact that isolated, sporadic attempts at river, stream or watershed control so frequently create problems as urgent as those they seek to solve.

Likewise the uses of water are intimately interrelated. Water control usually attempts to promote the beneficial uses and to diminish the harmful effects. To promote one use may destroy



another, or may increase the danger of flood, erosion, disease or drought. The reduction of one hazard may increase another, or destroy a beneficial use.

In few aspects of modern life is a comprehensive view more essential than in the development and administration of water resources. Where one use may interfere with many, or the improvement of one aspect of a watershed prove deleterious to many other aspects, proposed uses or improvements warrant most careful study. The factors requiring consideration are not limited to any single reach of a river, nor, indeed to the river itself. It is doubtful if a sufficiently comprehensive view is afforded by any unit less than an entire watershed. When this view is taken the soil-water-vegetation relationship becomes more pronounced. Forests no longer become only stands of saw-logs or fuel or pulp, but are revealed as gathering places of snow and as natural regulators of run-off and stream flow. Natural grasses on cultivatable fields and steep slopes represent not only prospective grazing areas, but soil binders, guardians against too rapid run-off with the consequent erosion, gullying and stream siltation. Flood plains in river valleys are not only fertile fields that may be drained but they are also found to afford protection against flooding on the lower river reaches. Swamps and marshes are seen to be not entirely waste lands but may, by their slow drainage, act as natural flood protection reservoirs, as replenishing areas for ground water and as habitat for innumerable fur bearers and waterfowl. Ravines and runways are not only impediments to travel and the means by which water is carried too quickly from where, in some years it may be needed, but are the means also of saving rich lands from flood damage in other years. Rivers are not only convenient scavengers but are also essentials to the well-being



and happiness of large numbers of people.

Forested areas may be denuded and steep grassy slopes improperly cultivated, but only at the cost of more irregular stream regimen, increased erosion, stream siltation and soil and water wastage. Natural flood plains may be protected against floods, but usually at the cost of increased flood hazard elsewhere. Swamps and marshes may be drained, though frequently to provide but poor land for agriculture and sometimes to deprive valuable waterfowl and fur bearers of their homes, rivers of their natural reservoirs and ground water supplies of their sources. Ravines and creeks have been dammed for water supply or obstructed by railway or highway grades, and periodic floods have been made more devastating on that account. Manure, dead livestock, raw sewage and industrial wastes have been disposed of into streams and the health and well-being of other communities thereby prejudiced.

It is as important that water resources be considered in relation to a comparatively long term of years as it is that they should be considered in relation to a sufficiently comprehensive area. The amounts of precipitation, run-off, ground water, and surface storage vary widely from year to year. Drainage problems of one year may be superseded by irrigation problems the next. Floods may alternate with drought and high water tables with dry wells. Low lying lands may be swampy wastes for a period of years, and during a succeeding time provide the only fodder available over a large district. The mind of man is much impressed with that which is recent. As a result there has been a tendency to over-emphasize the importance of drainage after a period of wet years, just as the importance of drainage and

the drainage aspects of stream channels may be temporarily forgotten after a period of dry years.

Despite the apparent conflicts in stream and water use, and the intricate cause and effect relationships that so frequently defeat the purposes of inadequately planned stream and water control, and despite the wide variations in water conditions from one year to the next, limited water resources can be so administered and developed that their usefulness may be greatly increased and the standard of life and degree of security of those dependent upon them correspondingly enhanced.

Of fundamental importance to the sound development and administration of limited water resources is an understanding of the characteristics of the watershed, the meteorological and hydrological conditions prevalent over the area, the geological conditions affecting underground supplies, and the topographical and vegetative conditions which may affect these and which so largely govern the various uses for which water is required or to which it may be adapted. It is important that the data which are essential to the understanding of any watershed be planned and collected in a comprehensive manner. Not only must the area considered be of sufficient extent to include all the governing conditions, but the period continuously covered by the meteorological and hydrological data must be sufficiently long to indicate all probable variations.

If any one feature of our natural resources is to be placed before others, probably it could be most reasonably urged that a fertile condition of the soil is the most important natural asset to be safeguarded, because, for his sustenance on the earth, man requires food, raiment and shelter, and these essentials are supplied him in

one form or another, either directly or indirectly, from the soil. Soil without moisture is of no use in providing and maintaining a vegetative cover for water is an essential constituent of plant life and is also required to make available those elements of the soil necessary as plant food. Vegetative cover increases water infiltration and reduces direct evaporation losses of soil moisture. It is therefore by proper agricultural and forestry practices that the most direct beneficial results can be obtained in conserving and utilizing the yearly precipitation.

In carrying out a co-ordinated program for the conservation and utilization of soil and water resources, certain fundamental objectives should be sought.

1. Every effort should be made to prevent erosion by slowing down wind and water velocities so that it cannot blow or wash away the top soil.
2. Every effort should be made to promote the absorption capacity of the soil so that more water will soak into the underground storage.
3. Every effort should be made to realize all beneficial uses of water by constructing wherever feasible ponds and reservoirs and by controlling small streams.

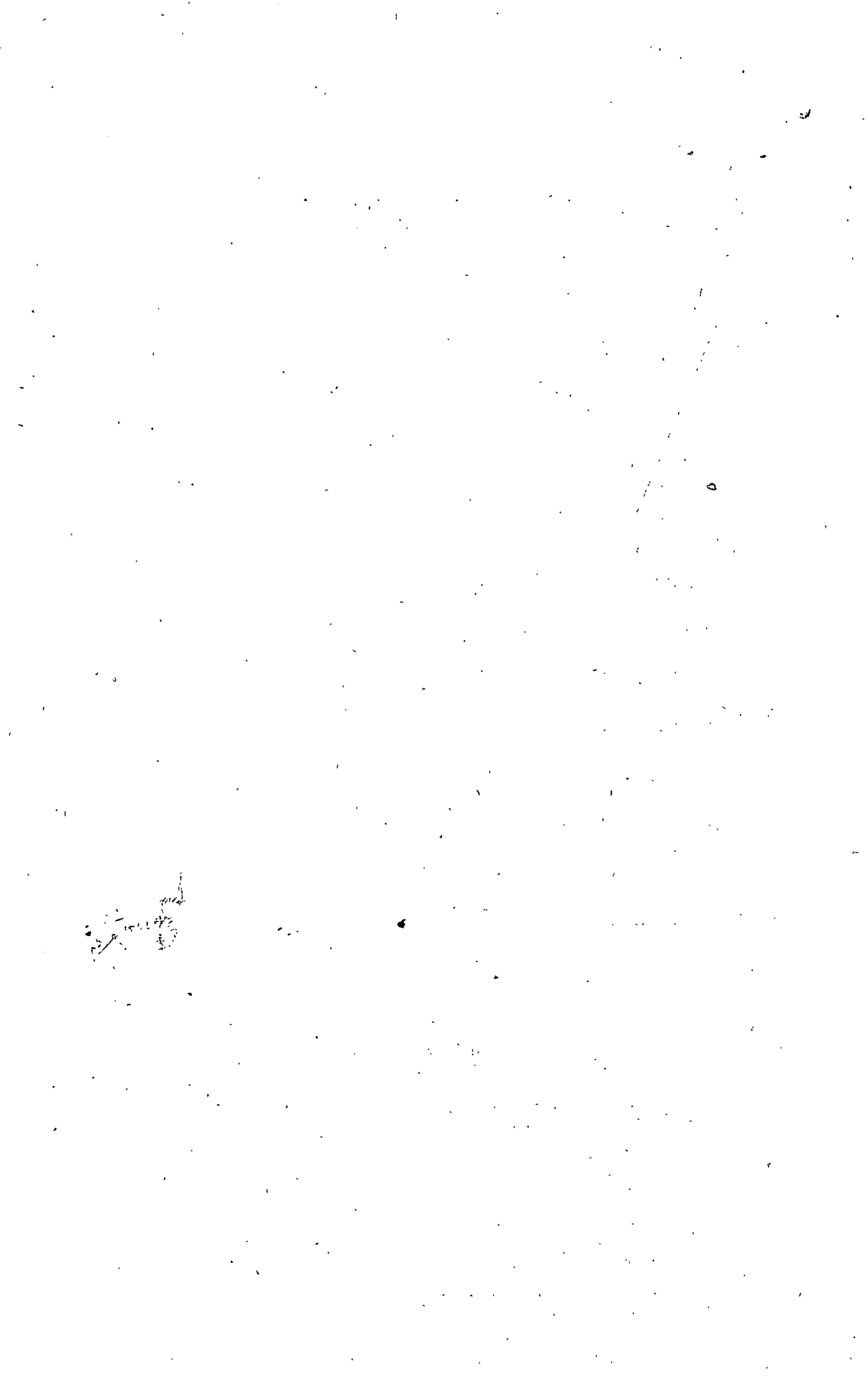
The execution of such a conservation program would not only reduce the menace of soil erosion and produce many new and immediate benefits but it would contribute to the control of floods on the smaller streams and in some degree on the main rivers. By promoting the absorption capacity of the soil through vegetative cover and farming methods, much of the water that now runs off quickly to the streams will be retained on the land where it falls. As a result, this water may not reach the rivers all at once and some of it may never reach them.

Water power has played an important role in the industrial and mining development in the province and in supplying the varied conveniences and comforts of community life. Its development and use have kept pace with the steadily growing demand. The existing developments with a present installation exceeding 400,000 horse-power and an ultimate capacity of nearly 600,000 horse-power serve not only the City of Winnipeg and surrounding municipalities with low cost power but also the cities and towns of southern Manitoba and the mines of central and north-eastern Manitoba.

From reconnaissance investigations already made and from other existing data which have been collected and co-ordinated, it is estimated that the undeveloped water power available exceeds 4,000,000 horse-power under conditions of ordinary minimum flow and 6,000,000 horse-power ordinarily available for at least six months of the year.

The potential power resources of the province are widely distributed in the Pre-cambrian Shield and are so situated that they become a valuable adjunct to the future development of the forest and mineral resources of this area and of industries associated therewith. Long distance transmission of electricity and increased markets for power in the southern part of the province make these power sites a valuable reserver of hydro electric power resources for future development.

An accurate inventory of the power resources with a view to their maximum development and proper utilization is only attainable by a co-ordinated plan in which each developed site forms a component link in a comprehensive scheme looking to the development of the entire river system. To accomplish this it is necessary that a



planned program of survey and investigation be followed each year to accurately survey the power and storage facilities of each watershed, together with the establishment of gauging stations to obtain an accurate record of the run-off over a period of years.

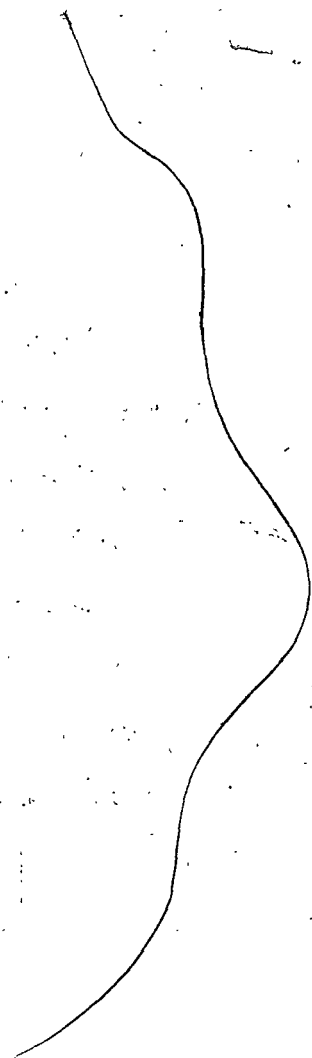
As the initiation of any power development requires a foreknowledge of all pertinent data, it is essential that these be available well in advance of construction. Only in this manner can administrative control of our water powers be made effective with a view both to the conservation and the promotion of their most advantageous use.

A review of the factors presented in this report leads to several important conclusions.

1. The proper planning for the conservation and best utilization of our water resources requires as its first essential that adequate data be available.
2. The long term average of approximately two per cent of the precipitation which leaves the prairie watersheds each year in the form of run-off is not likely to be appreciably altered.
3. Evaporation control, when viewed broadly, is practically limited to methods of soil culture and vegetative control, or, in other words, to agricultural and silvicultural practices.
4. While actual drought conditions end for most vegetative cover as soon as the soil moisture content rises well above the wilting point, the drought is not completely ended until the soil moisture is restored to field moisture capacity and sometimes longer. It may, therefore, take a year or several years to restore ground water storage to normal.

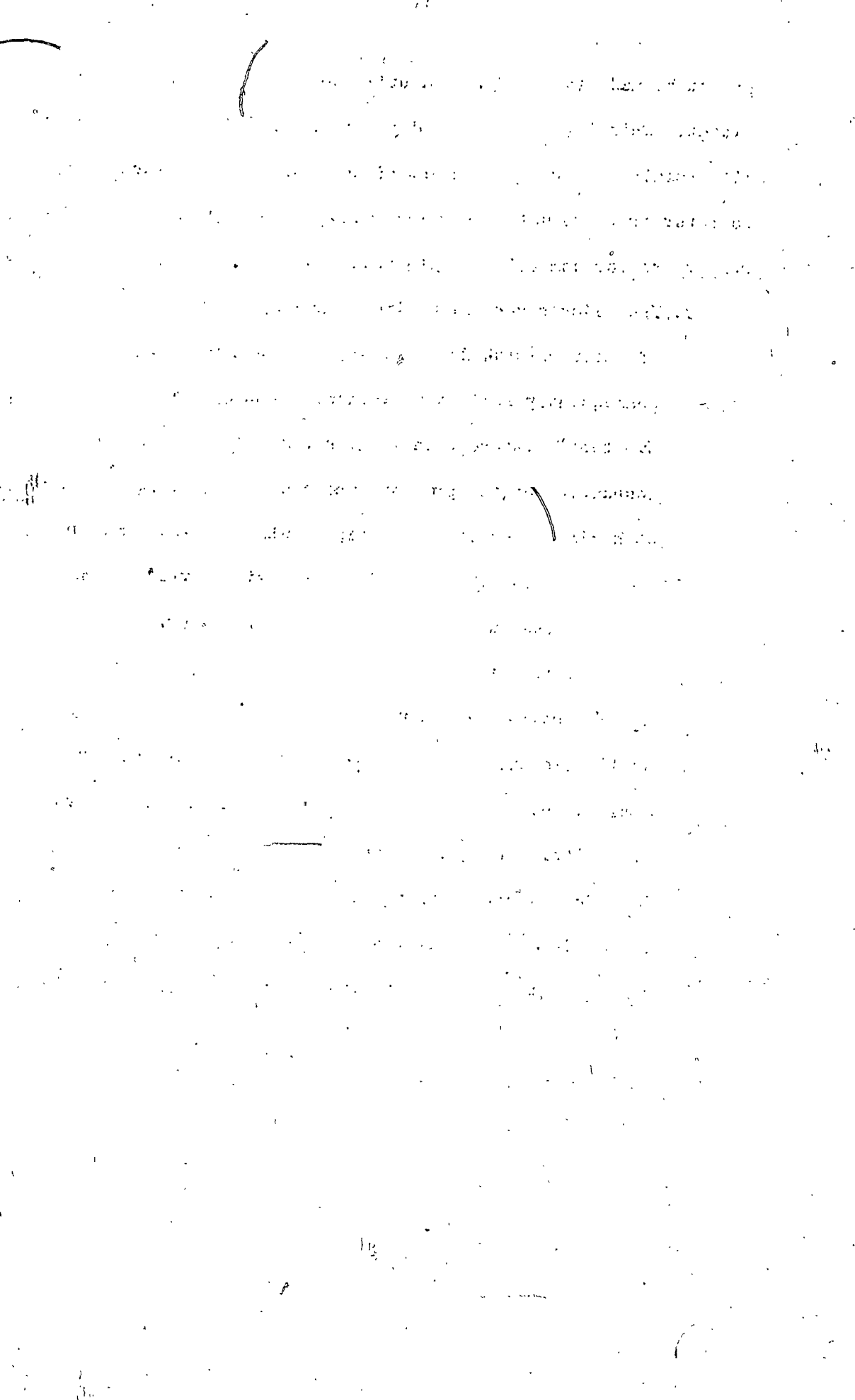
In the meantime wells are low and stream flow falls off quickly during periods of low precipitation.

5. In general the proper handling of ground water supplies can advance along two closely related lines. The first involves the elimination or control of whatever wasteful or harmful practices are known to exist. The second involves the earnest pursuit of accurate and adequate data relating to quantity, quality, rates of replenishment and dependability of available supplies.
6. For several reasons irrigation is unlikely to have any wide application in Manitoba. The fact that in normal years the run-off from prairie watersheds amounts to only about two per cent of the precipitation is a clear indication of the limits naturally imposed upon extensive irrigation. During exceptionally dry years, when the need for additional moisture is particularly great, the quantities of water available are appreciably less.
7. The problem of the best utilization of marsh lands should depend for its solution upon a complete investigation to determine the highest economic utility inherent in such lands. Such lands may reach their optimum use as hay lands, as partially improved lands, as reclaimed agricultural lands or as preserves or sanctuaries for waterfowl and fur bearers. The productivity of any of these lands for these uses may involve complete drainage, drainage during a part of the season, water level stabilization or flooding to additional depths.
8. In the generally more arid portion of southern Manitoba where the maximum degree of prosperity attainable is largely dependent upon the optimum use of water, it is essential that every



effort be made to conserve and utilize it to the fullest possible extent. This involves the employment of such farming methods as will retain the greatest amount of the available moisture in the soil for crop production combined with the construction of small reservoirs for domestic and stockwatering uses.

9. The major rivers of Manitoba have by far the greater portions of their watersheds lying outside the province and are consequently subject to a large measure of outside control. Manitoba's interest in these rivers extends beyond the boundaries of the province and can best be safeguarded by maintaining her essential rights while at the same time co-operating with the other interests with a view to the ultimate best use of all the available water.
10. In the interest of economic and co-ordinated control and administration of the water resources and their greatest utilization all Acts relating to water should be reviewed, revised and consolidated to provide one administrative authority. This authority should be charged not only with the administration of these resources but also with the collection and compilation of all the physical and hydrological data essential to proper planning and control.



CHAPTER 1

WATER RESOURCES OF MANITOBA

INTRODUCTION

The source of all water on or within the earth, useful for the activities of man, is precipitation which results from the condensation of atmospheric moisture in the form of rain, snow, hail, dew and frost.

Probably nowhere on earth is there such an extended and continuous record of civilization to be found as in the lower valley of the Nile. Nowhere has water played a more dominant role amongst men and nowhere has water been more systematically put to its manifold uses. While the Nile nurtured Egypt, the Egyptians cared well for the Nile and formed habits that agreed with their philosophy about water. Pollution became a sin and waste a crime.

As civilization spread to the more humid regions of Europe where man found sufficient water in the rivers and brooks, lakes and marshes, and issuing from springs in the mountain sides, and besides all this, abundant and sometimes devastating rainfall, where floods were more frequent than droughts, the philosophy of man toward water changed materially and water became something to be rid of quickly.

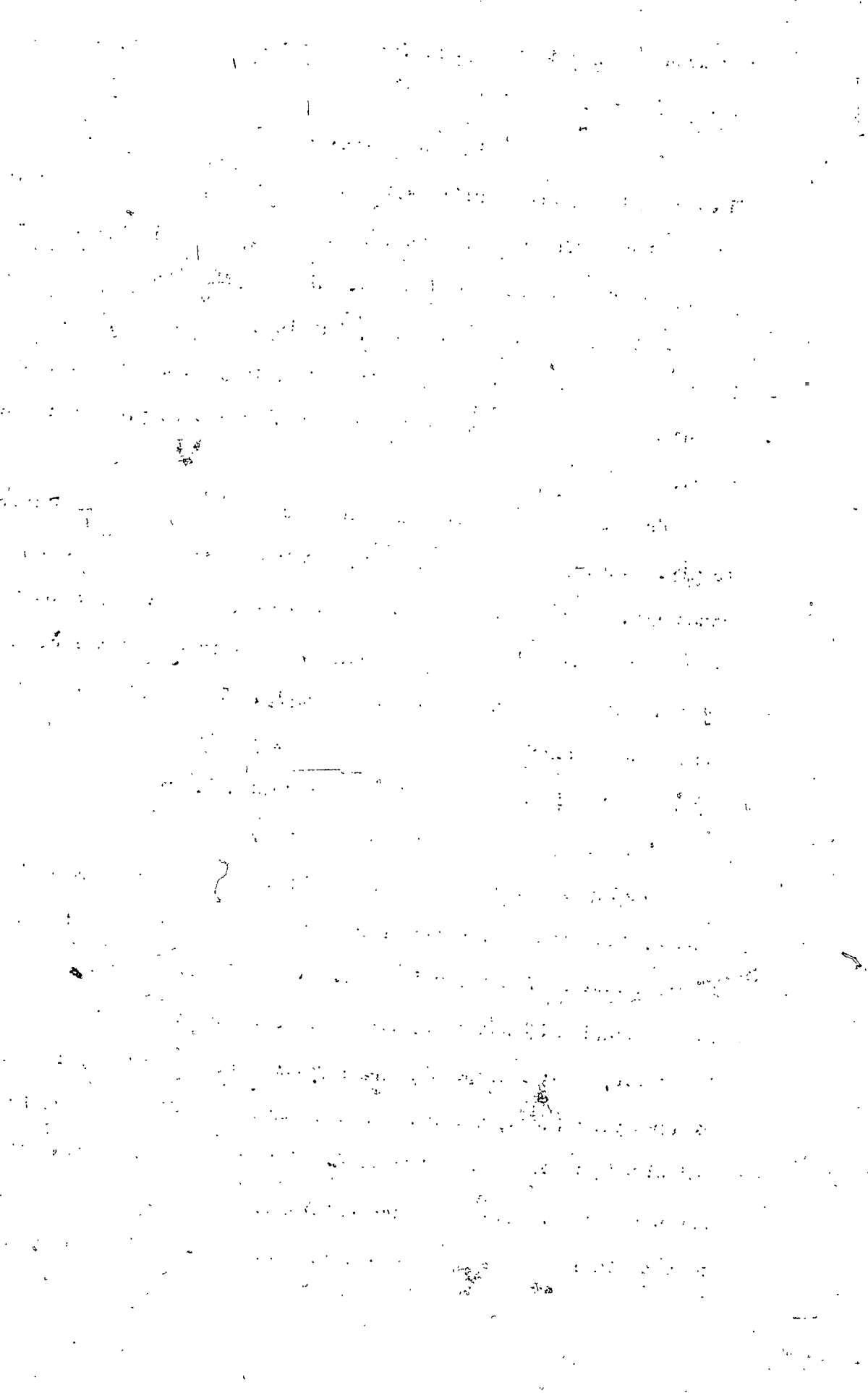
Since earliest times man has utilized the power of flowing water. Along the Yellow, the Nile and the Euphrates, evidence has been found that the power of these rivers was utilized, chiefly for irrigation purposes. One of the earliest European water power developments of which there is record was on the Thames River near London Bridge. This was a float wheel constructed in 1581, which

was used to operate the pumps for the first water supply for the city of London.

It was no mere coincidence that the earliest civilizations flourished along the fertile valleys of rivers and that the greatest, most powerful cities were founded along their courses, frequently where they reached the sea. Not only did the rivers form the valleys and make them fertile, but in hollowed logs, rafts, junks and steamships - all down the ages, they have carried the products of land and water - the commerce of the people who lived there.

From the human standpoint water is second only in importance to air. Water, to a large extent, determines the health of any community. The standard of health in ancient Rome was far above that of plague-ridden mediaeval Paris, and this historic fact was not without some relation to water supply. The famous aqueducts of ancient Rome carried to that city approximately fifty gallons per day for each of its one million inhabitants. Paris in 1550 used approximately one quart per capita per day.

During the early stages of exploration and development in Canada, the lakes and rivers formed the main highways of travel and transportation of settlers' goods. As the country became more fully occupied by settlers, problems of water supply, flood damage, low water, sewage disposal, stream pollution, irrigation, drainage of low lying lands, water power and stream crossings for railroads and highways became more pressing. Cities have built aqueducts for hundreds of miles to reach watersheds which could be protected from contamination and have likewise obtained their electric current



in many cases from waterfalls at similar distances. Towns, mines and factories disposed of their waste by dumping it into the rivers, which threatened the health of the inhabitants in the lower reaches. As the place of water resources in our national life has changed with the country's development, so it is likely to change further in centuries to come.

The more interdependent we become as individuals and communities, the more do we need to plan the uses of our water resources with all our interests in mind. Our attention cannot be confined to rivers and lakes, as underground waters are the chief reliance of our population in many areas. These underground water supplies are influenced to a degree that we cannot yet accurately determine, not only by the sinking of wells and the rate of pumping, but also by lumbering, grazing, tillage and drainage, which influence evaporation, plant absorption, run-off and seepage into the deeper strata.

Water always has been and always will be the major factor in the development of civilization which can exist or expand only where an ample and reliable supply is available. There have been few scientific developments that have not had some relation to water. The steam engine introduced an era of new industrial processes and in so doing made important demands upon water. The power loom, the spinning jenny, the railway and steamship offered new uses for steam and hence of water. Current mining practices, paper manufacturing, packing, canning, dyeing and a score of other modern processes have important relations to water supply. Water wheels taking their power from rivers have been amongst the earliest sources of inanimate power. The distance over which this power was available was,

The first part of the document is a letter from the President of the United States to the President of the Senate, dated January 1, 1877. The letter is signed by Rutherford B. Hayes and is addressed to Charles Schreyer. The letter is a copy of a letter that was sent to the President of the Senate by the President of the United States. The letter is a copy of a letter that was sent to the President of the Senate by the President of the United States. The letter is a copy of a letter that was sent to the President of the Senate by the President of the United States.

until recently, limited to the lengths of the shafts and belting. The cumulative work of hundreds of scientists has extended this distance to hundreds of miles; has enhanced the value of rivers remote from civilization and the responsibilities of those who are charged with their administration and development. In planning for water utilization the country must, therefore, take a long view and that in terms of conservation as well as in terms of current use, for when one substance determines the standards of health, prosperity and culture to which any community might attain, it behooves that community to examine closely the manner in which its continuous best use may be assured.

The problem of utilizing and obtaining the maximum benefit of the water resources of Manitoba is not only complicated by local settlement and physical characteristics within the province, but also by the fact that the sources of the water supply extend for many miles to the west, to the south and to the east of the provincial and international boundaries. While Manitoba is bountifully endowed with lakes, rivers and streams, the watersheds of the larger streams and lakes extend west to the Rocky Mountains, two hundred miles southerly in the United States and easterly to within fifteen miles of Lake Superior and comprise a watershed area outside the province greater than the total area of Manitoba.

Planning the utilization of this water to the maximum benefit of the citizens not only depends on long term planning and proper utilization in each local watershed for domestic, agricultural, industrial, power and fishery uses, but likewise upon some mutual agreement regarding the control over the diversion of waters within the watersheds lying outside the boundaries of the province.

CHAPTER 11

HYDROLOGIC FACTORS

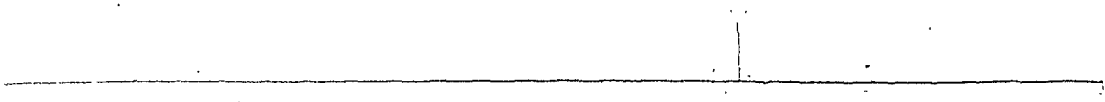
THE HYDROLOGIC CYCLE

All natural resources are made available by natural processes, gold and iron, coal and petroleum no less than forests, fish, fur and waterfowl. It is of interest and use to the geologist and mineralogist to know the geological forces that caused the placement of minerals. It is of the utmost interest and importance to the forester, the biologist and agriculturist to know how nature, in its organic forms, can renew itself. Water, which serves a fundamentally important function in geological and biological processes, is, in its relationship to land, being constantly renewed. Quantitatively, the forces acting upon water during this process are of an almost infinite variety and are at present little understood. Many of the amounts concerned are widely variable and are extremely difficult of measurement. Qualitatively, this process is of a form which, in main outline, has been fairly definitely determined. It is known as the Hydrologic Cycle. Any phase of this cycle may be arbitrarily chosen as a starting point for descriptive purposes and in this instance it is convenient to start with atmospheric moisture.

Atmospheric moisture consists of water vapour which is a gaseous state of water and is present in the atmosphere because of evaporative processes from land and from water. Water in its gaseous state is lighter than air at normal land level densities and hence has a tendency to rise. Air will support varying propor-

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tions of water vapour depending primarily upon its temperature and experiments show that air at 100° Fahrenheit will support almost ten times as much vapour as air at freezing temperature. When water vapour in the atmosphere is cooled, condensation results to form precipitation which may take any one of several forms depending on atmospheric conditions. Precipitation may condense in the form of small water particles in the upper air and fall in the form of rain. If the raindrops fall through zones or layers of air with freezing temperatures, they reach the earth as hail. The vapour may freeze immediately upon condensing and fall as snow. The vapour may precipitate only when the air contacts cooler surfaces and may be deposited as dew, or condensation may take place on the surface, the temperature of which is below the freezing point, in which case frost is formed. Some precipitation while falling may pass through layers or zones of dry air and be evaporated before reaching the ground and immediately replenish the atmospheric reservoir. This is known as ineffective precipitation. Some precipitation is intercepted by vegetation and evaporates back to the atmosphere. This process is called interception.

Of the precipitation which reaches the ground some seeps into the soil, some runs off over the surface and some evaporates. The first tendency of rain or melting snow is to moisten the ground surface and then to percolate into the interstices of the soil. The proportion of the precipitation thus disposed of varies greatly with the temperature and with the previous water content of the soil. If the ground is frozen or if the soil is well saturated with water, very little additional water may be admitted. Some portion



of the water which enters the soil is carried back toward the surface by capillary action and evaporates directly from the soil surface. Some of the soil water enters the root systems of trees, plants and other forms of vegetation and is utilized by them in producing growth and maintaining life and then passes through their pores into the atmosphere as water vapour. This is called transpiration.

If the amount of water which enters the soil exceeds the combined requirements of transpiration, soil surface evaporation and soil absorption, the excess may seek the lower levels and enter the ground water reservoir. This process is known as infiltration or percolation.

Evaporation is the process by which water, when subjected to heating by solar energy or otherwise, changes from liquid or solid form into a gaseous state. Of the total precipitation a very large amount falls directly upon the ocean and large inland lakes and other water surfaces such as rivers, ponds, sloughs, etc. Practically all such precipitation is ultimately evaporated into the atmosphere and becomes part of the atmospheric moisture. In the Arctic and northern portions of the Temperate Zone, evaporation from water surface is frequently less than precipitation. Elsewhere the evaporation from water surfaces is generally equal to, or greater than, the precipitation.

The elevation of the water in the ground reservoir is known as the water table. Ground water circulates by moving along the dip of various pervious strata such as sands, gravels, various porous rocks and through fissures.

The water-bearing strata called aquifers may alternate with layers of clay or other impervious material to form a series of water horizons. Where any ground water horizon lies above a stream bed and fissures or porous materials allow it to escape, it enters the stream and it is from this source that river flows are provided during periods of low precipitation when there is little or no surface run-off. The fact that ground water moves slowly accounts for the uniformity of flow in certain streams which are largely dependent upon ground water supplies.

When the rate of precipitation exceeds the rate at which water may be absorbed into the soil or detained in minor depressions, surface run-off occurs. This part of precipitation, generally referred to as run-off, finds its way over the surface of the ground until it reaches a definite stream channel and ultimately the ocean. There is, however, some loss in transit due to evaporation and infiltration.

From the foregoing it will be observed there are three great natural water reservoirs. By far the largest of these is the surface reservoir comprising oceans, lakes, marshes and rivers. The next in point of capacity is the ground reservoir, while the most active and variable of the three is the atmospheric reservoir. It is from one of these sources or from any one of the numerous stages of transition from one to the other that water for any of the purposes to which mankind seeks to adapt it must be obtained.

The cycle of precipitation, infiltration (percolation), run-off, evaporation and condensation to precipitation again may appear an obvious and simple natural phenomenon, and while the factors which make up this life-giving cycle are well known, very little is known

of the relationship between them. In the first instance, the elements of this cycle vary enormously, not only throughout the country, but from year to year and from season to season.

VARIATIONS IN HYDROLOGIC PHENOMENA

The rapidity with which the hydrologic cycle recurs is widely variable over different parts of the earth and, from time to time, over the same parts. In general the fundamental causes of variations in hydrologic conditions over certain wide areas of the earth's surface are thought to be:-

1. the uneven distribution of the sun's rays over the earth's surface;
2. the rotation of the earth upon its axis;
3. the inclination of the earth's axis;
4. the unevenness of the earth's crust (relative positions of mountains, oceans, etc.)

The uneven heating of the earth's surface causes an upward movement of the air along the zones of higher temperature and an in-rush of air from below toward the zones of greatest heat. Thus there is a general movement of the lower air toward and of the upper air away from the equator. The upper air, moving away from the equator descends in the vicinity of latitude 30° to 40° and causes belts of calm. Due to the higher pressures created this air moved outward, part toward the equator and part, less regularly, toward the poles.

The winds blowing toward the equator are the two trade winds. Originally blowing north and south they are deflected by the rotation of the earth and are thus in the northern hemisphere north-easterly and in the southern hemisphere south-easterly in direction. The winds blowing toward the poles are the prevailing westerlies, or the north-west and south-west variables, respectively.

The continents of North and South America lie athwart these wind belts and along the western edge of these continents is a fairly continuous mountain chain. As the trade winds sweep across the Caribbean Sea and the South Atlantic Ocean toward equatorial South America they are increasing in temperature and hence in moisture carrying capacity. The gradually westward rising land surface of South America forces the hot winds upward. The higher the elevation, the less dense the atmosphere becomes and the lower the temperature drops. This gradual cooling of the air causes precipitation. By the time the air has been forced upward to the elevation of the Andes, where it frequently reaches temperatures below freezing, very little of the original water vapour is retained. Upon crossing the mountains, the air moves down the western slopes, becoming denser and warmer through compression. That part of equatorial South America west of the Andes is continually swept by hot dry winds. In general these processes account for both the extremely heavy precipitation in the Amazon valley and the extremely dry climate of the Peruvian desert.

With diminishing effect similar conditions obtain from the equator north to the vicinity of 30° north latitude and south of the equator a similar distance. North and south of these parallels respectively, the prevailing westerlies, sweeping the Pacific, are forced suddenly upward upon striking the western slope of the mountains. The resultant expansion causes a cooling of the air and heavy precipitation along the western slopes of the Andes and Rocky Mountains. The warm dry air sweeps across the western prairies of North America and the pampas of South America to cause sub-humid or semi-arid conditions. The Chinooks, common on the western Canadian prairies, are typical of the warm dry winds which not only

[illegible]

carry very little moisture but which cause high rates of evaporation.

These general phenomena would appear to account for certain broad climatic classifications and resultant vegetative conditions such as;-

- (a) the heavy rainfall east of the mountains between 30° south and 30° north latitude;
- (b) the desertic conditions west of the mountains in this same zone;
- (c) the heavy precipitation west of the mountains in southern Chile, the north-west Pacific States and western British Columbia;
- (d) the sub-humid or semi-arid conditions over the north-western plains regions of North America and the pampas of Southern Argentine.

In contrast to the general agreement as to the causes of climatological variations in different parts of the world is the wide divergence of opinions as to the causes of variations from year to year. The earliest civilizations have recorded annual variations in lake levels, river flows, amount and incidence of precipitation, as well as early and late seasonal changes. Although records have been obtained for several centuries, in the case of the Nile for almost 3,000 years, and by tree-ring analyses for upwards of 5,000 years, there is no evidence that any major climatological changes have occurred during this brief space of geological time. The causes of the year to year fluctuations have been the subject of much investigation and attempts have been made to correlate them with almost every newly discovered atmospheric, solar or planetary phenomenon but a review of the various theories that have been advanced or are at present under investigation would serve no useful purpose here. It is sufficient to observe that there has occurred, for as long as history can witness, periodic variation in precipita-



tion; that the time consumed in any one period of high or low precipitation appears at present to be highly variable; that every reasonable indication points to the recurrence of periods of relative plenty and scarcity of precipitation; and that there is insufficient evidence upon which to assume any continuous upward or downward precipitation trend with respect to any area so far investigated.

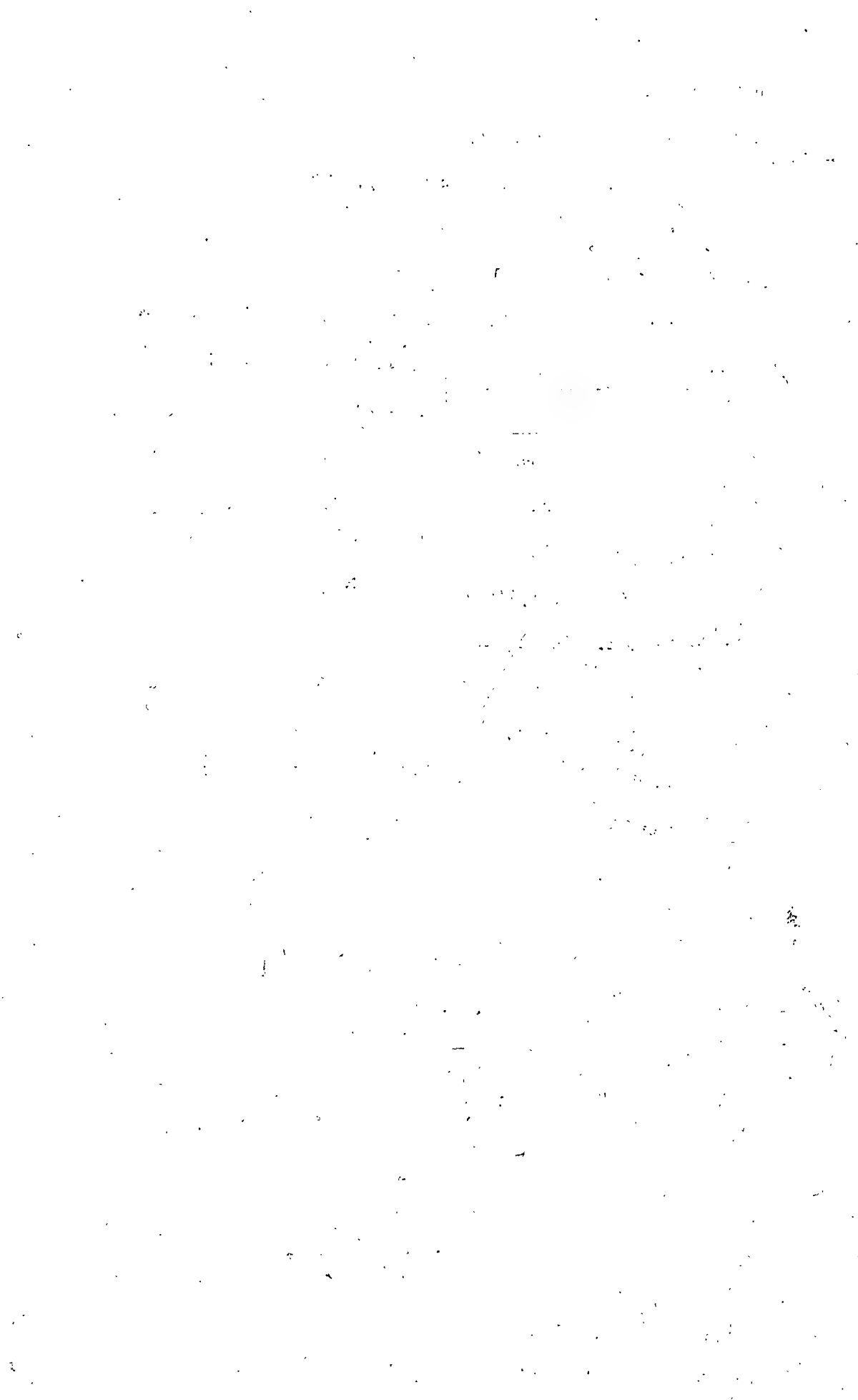
Naturally the greatest source of moisture is the tropical regions where there are enormous water areas and high temperature. On the other hand the lowest evaporation occurs in deserts and in the arctic regions where it is very cold and largely continental. As the air receives its supply of vapour by evaporation there is continually passing into the air an enormous quantity of moisture from evaporation and this moisture is distributed by the air currents over the face of the earth. The problem is, how is this moisture to be taken out of the atmosphere? High mountain ranges are one means of accomplishing this. Polar air currents are another. The comparative aridity of the western Canadian prairies is chiefly conditioned by the position of the Rocky Mountain system in relation to the prevailing winds. Precipitation is caused primarily by the cooling of moist air and its occurrence indicates that moist air has been acted upon by some cooling agency. Competent meteorologists by patient observation and study have found that there is a definite amount of moisture that can exist in the form of vapour for any given temperature, that temperatures decrease with height above the earth's surface and that huge masses of air of great depth develop uniform physical properties over a number of source regions in North America.

Conditions existing

in the upper atmosphere have been the subject of long investigation and it is now known that there exist, in the temperate regions of North America at any rate, two great air masses or air currents. These are known as the polar current or polar air mass and the tropical current or tropical air mass. The polar air current originating in the polar regions and Arctic tundra of northern Canada is cold and comparatively dry whereas the tropical current originating in the vicinity of the Caribbean Sea and the Gulf of Mexico is warm and generally moist.

While there are many different types of air currents, generally speaking it is these two air currents that are chiefly responsible for precipitation in Manitoba and the prairies of western Canada. The polar air currents move in a southerly and southeasterly direction across the continent, and, being heavy, flow along the surface. When a tropical air current approaching from the south collides with the polar air current, the lighter and moister air advancing from the south is forced to ascend to higher levels and as it cools it condenses and yields moisture by precipitation. The abundance of rainfall in the region depends upon the amount of moisture in the air and the degree of cooling to which it is subjected. This will determine whether it is mere drizzle, moderate rain or heavy rain, or light or heavy snowfall, while the duration of the rainfall will depend upon the period in which these two air masses are in contact in any given region or locality.

Rainfall in any appreciable amount cannot occur in a region which is entirely under the influence of either the tropical or polar current. Thus when drought conditions appear, either one or other of these currents is very weak, and generally this is the

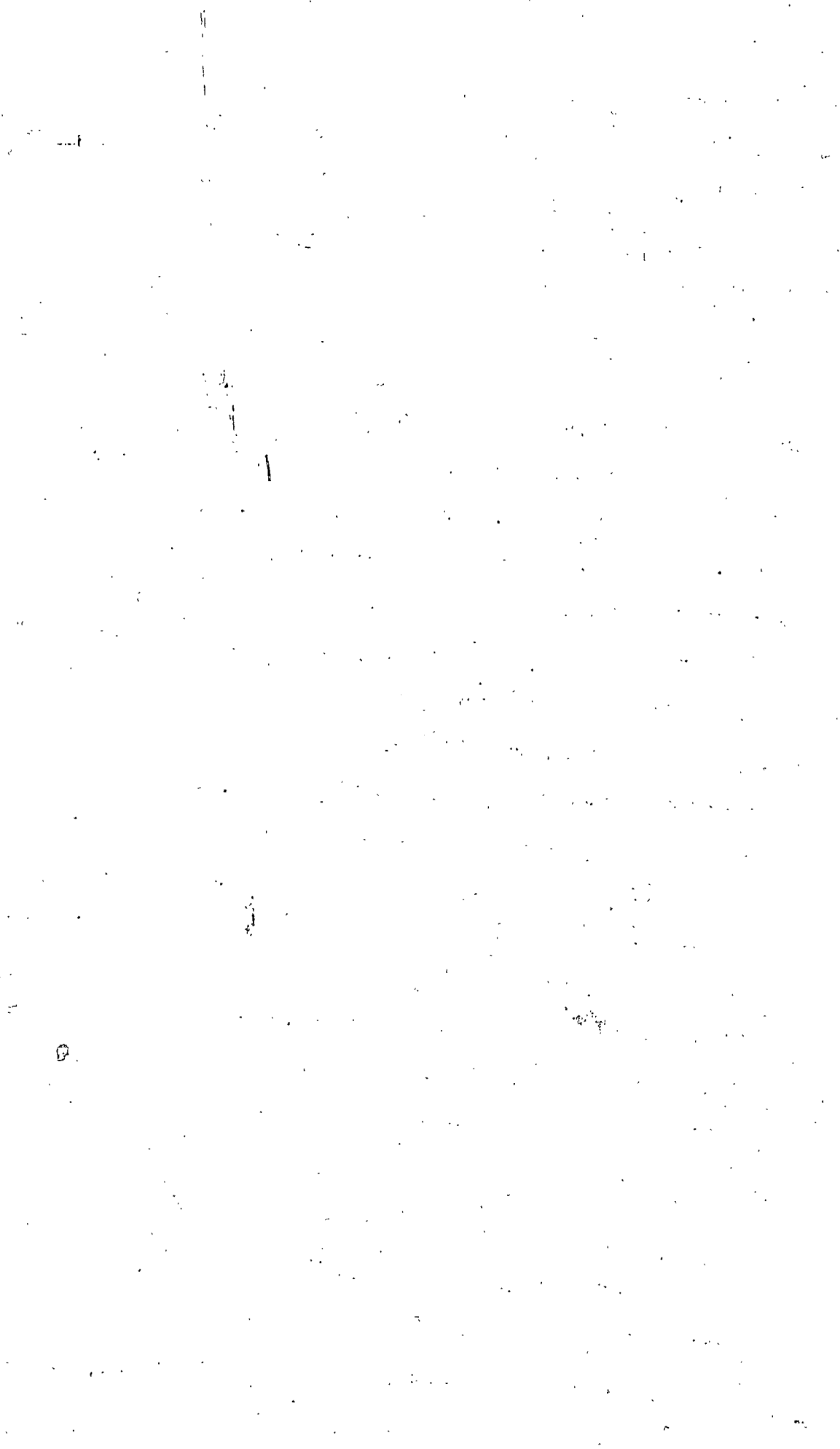


polar current so that the prairie regions are largely under the domination of the tropical or warm air current during the years of drought. This being the case, there is usually more moisture in the air per cubic foot than there is in the years of good rainfall but as there is no means by which the ascension of the air can be forced, there is in consequence no precipitation.

Upon the basis of the "polar air" explanation, less than normal precipitation may be accounted for in either one of two ways. Either there is a deficiency of warm moist air or there is a deficiency of polar air. After a careful examination of the relevant data, Mr. J. Patterson, Director of the Meteorological Service of Canada, found that the recent period of severe drought in western Canada was characterized by high relative humidity and comparatively high temperatures, whereas satisfactory precipitation had occurred during years of low relative humidity and relatively low temperatures. From these investigations, Mr. Patterson concludes that in western Canada, the presence of polar air is usually the controlling factor with respect to precipitation. This would indicate that there is normally present sufficient moisture to produce satisfactory precipitation. On the basis of Mr. Patterson's investigations it appears safe to conclude that periods of deficient precipitation have very little, if any, relation to local evaporation or such other factors as may be subject to control by human agencies.

PRECIPITATION AND RUN-OFF

The meteorological records show the normal annual precipitation in the southern part of Manitoba varies from twenty inches in Winnipeg to about sixteen inches along the western boundary and that about half of the total precipitation falls during the months of June, July and



August. These records show the extremes in precipitation are nearly fifty per cent above or below the normal, that is, the minimum precipitation may only be one-half the normal for the region, while the maximum may be one and one-half times the normal recorded in that region.

Neglecting precipitation in the form of snowfall and considering the rainfall only which more directly affects crop growth, long term records of rainfall in Manitoba show an average of approximately $13\frac{1}{2}$ inches. In this long term period there were five years when the rainfall on the average was less than 9 inches or what might be termed years of severe drought. The driest year in Manitoba was in 1931 with slightly less than 8 inches and the wettest year in 1901 with approximately 22 inches.

The amount of evaporation from the water surfaces during any year may be termed the evaporation potential.

This figure gives some indication as to the amount of water which would be evaporated if it were continuously available. Over the prairie portions of western Canada the evaporation potential is variously estimated at between twenty and thirty inches per year.

The fact that the evaporation potential exceeds the mean annual precipitation would indicate that all precipitation would be evaporated if it were continually available for this purpose. Any excess of actual precipitation over actual evaporation must be represented as soil or surface storage or as run-off. Of these, run-off is the only one which has been systematically measured from year to year. Assuming there is no continuous long term upward or downward trend with regard to surface or ground water storage, it follows that the actual evaporation over the watersheds is represented by the difference between precipitation and run-off. An analysis of

stream flow records of run-off for the watersheds of the prairie regions of western Canada has led to the conclusion that approximately 98% of all precipitation is evaporated and that the remaining 2% is expressed as run-off.

Run-off in the ordinary sense is the difference between precipitation and evaporation. The total amount of run-off in any year is conditioned to some extent by the total amount of precipitation, but more directly by the time during which the precipitation takes place. A much larger proportion of an intense rain of short duration will find its way into the stream channels than would be the case if an equal amount of rain fell in several widely spaced showers or as a gentle rain.

Further analysis in precipitation and run-off relationships reveal the total run-off in western Canada is more directly influenced by winter than by summer precipitation. This is accounted for by the fact that a large proportion of all run-off is carried by the streams during the spring freshets and that these freshets are particularly high after winters of heavy precipitation. The extreme or flood stages in these streams are most likely to occur following heavy fall and winter precipitation, with a sudden change to high temperatures and with heavy rains during the spring break-up period. During this period the ground is usually frozen and consequently sealed against any significant amount of infiltration. High summer run-off is most likely to occur after heavy rains have fallen on soils which are in a saturated condition and which have in consequence a low infiltration capacity.

Although the annual run-off from any area approximates the difference between precipitation and evaporation, the run-off during any particular storm from any area is chiefly the difference between

precipitation and the sum of soil and surface storage. It follows that the storm run-off is increased or decreased according as the opportunity for soil or surface storage is increased or decreased. The amount of moisture which can be absorbed by any soil depends upon the type and condition of the soil and upon the length of time during which infiltration takes place. The longer the water remains upon the soil the greater the degree of absorption or infiltration. The time during which infiltration takes place may depend chiefly upon the slope of the surface and the condition of the surface with respect to minor depressions and vegetative covering. The more porous the soil, the flatter the slope, the more uneven the surface, and the more dense the vegetative cover, the larger is the proportion of soil absorption.

Up to this point run-off has been treated as the difference between precipitation and evaporation. There is, however, another aspect from which run-off may be regarded and that is as the sum of surface run-off and ground water flow. Any reduction in surface run-off is usually accompanied by increased infiltration which in turn adds to the soil or ground water reservoir, and is disposed of by transpiration and/or ground water flow. This relationship assumes that the soils in question have a satisfactory infiltration capacity. The exception arises when surface run-off is impeded over clayey or impervious soils. Many swamps and marshes are in this category and being underlain with impervious clays, they serve to increase evaporation without any appreciable effect upon ground water conditions.

Of all the hydrologic factors probably run-off is the most widely variable in the prairie watersheds. An examination of run-

off records for the Assiniboine River watershed above Headingly covering a period of twenty years, reveals that the average yearly run-off from the 62,760 square miles comprising this drainage area was equivalent to a depth of 0.252 inches or slightly more than one-quarter of an inch over the drainage area. The mean precipitation for this period as obtained from a direct average of the mean precipitation from twenty-one stations within the area drained was 16.3 inches. Thus over a twenty-year period the run-off from the area amounted to only 1.55 per cent or approximately one sixty-fourth of the precipitation.

During extremely dry years when the demands upon surface water are usually most urgent the run-off falls far below the mean. In 1931, for instance, the run-off from the Assiniboine River watershed amounted to only 0.04 inches (one-twenty-fifth of an inch) or less than one-sixth of the twenty-year mean. In the case of smaller streams which are usually more directly affected by purely local conditions the variation from the normal is likely to be even more pronounced.

An examination of the available records shows the average annual run-off for the prairie regions of western Canada to be approximately two per cent of the average annual precipitation. While from many aspects run-off is subject to control, no scheme or combination of schemes offers any hope of smoothing out the major fluctuations as to amount and the long term average of approximately two per cent of precipitation which leaves the prairie watershed each year in the form of run-off is not likely to be appreciably altered. It is this factor which must be kept constantly in mind when planning or considering projects for the conservation and

utilization of run-off of the prairie streams, the chief characteristics of which are relatively high spring and summer run-off, following the spring break-up and heavy summer rains, which dwindles to meagre proportions or to nothing during the late fall and winter months.

WATER, SOIL, AND VEGETATION RELATIONSHIPS

The amount and incidence of precipitation and the evaporation potential are the fundamental hydrological factors in western Canada and these must be accepted as beyond the control of human agencies to materially alter except in so far as these agencies address themselves to the intricate water, soil and vegetation relationship.

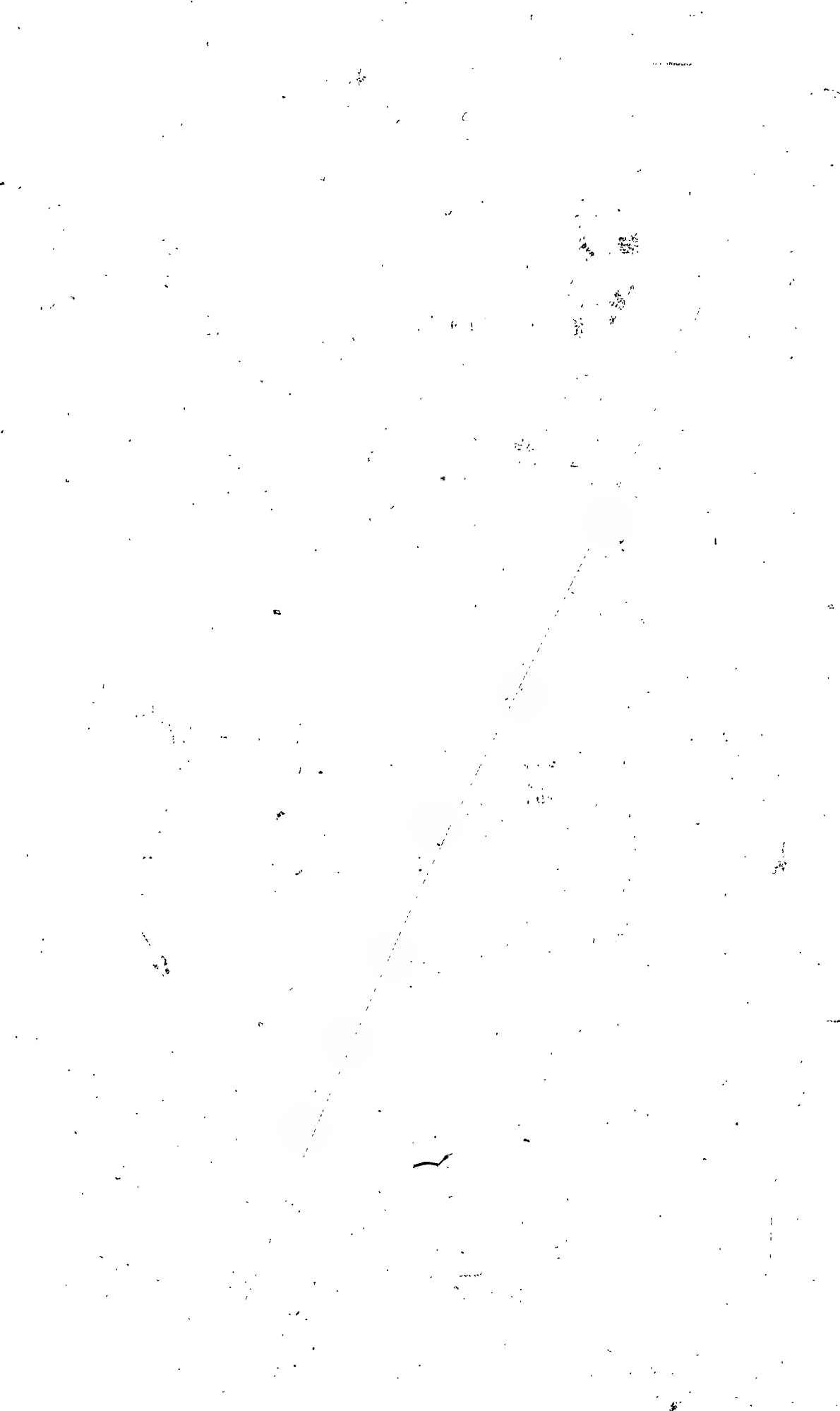
Since nothing can be done to change the amount of water falling on the land, attention must be directed to the greatest utilization of the water when it reaches the ground by increasing, if possible, the amount of water that will soak into the ground and decreasing the losses due to direct evaporation and run-off from the land. Run-off and soil losses are greatest under conditions where the soil is bare of vegetation and least from ground covered with forest, sod, grass, shrubs, etc.

The actual amount of evaporation from any surface or area, is conditioned by such factors as the amount of water in contact with the atmosphere, the temperature of the evaporating surface, the movement of air in contact with that surface and the vegetative cover. Control of evaporation is therefore limited to measures which may effect these conditioning factors. Water is carried to the surface by capillary action. This process and hence evaporation may be impeded by methods of tillage which produce a loose mulch in

the upper soil surface. The temperature of evaporating ground surfaces may be partially controlled by whatever control man may exercise over vegetative cover. Wind velocities have an important relation to the rate of evaporation by influencing the rapidity with which moist air is replaced by dry air. While the major air movements and wind velocities are the results of atmospheric pressure differentials and are beyond human control, the actual velocities of winds along planes of evaporation surfaces depend to some extent upon vegetation and forest cover, which, in turn, is subject to a large measure of human control.

Thus the extent of evaporation control, when viewed broadly, is practically limited to methods of soil culture and vegetation control or, in other words, to agricultural and silvicultural practices. The forest or other vegetative cover retards the flow of surface water and holds it longer on the land with the result that there is more time for the water to sink into the soil and a corresponding decrease in run-off. The effect of various types of vegetative cover on soil surface evaporation is largely off-set by increased transpiration requirements and from this relationship alone it might appear that soils under a vegetative cover would tend to be continuously drier than corresponding soils in an unprotected state.

Vegetative cover through its root systems provides greater infiltration capacity to the soil and it now seems to be well established that a good sod or grass cover is the most effective natural means of controlling run-off and preventing soil erosion and that it provides a high infiltration capacity due largely to the density of plant stems per unit of area.



Water in the soil available for plant use is that lying between the wilting point as a minimum and the field-moisture capacity of the soil as a maximum. When water enters the soil by infiltration it is all held in the soil above the water table until the soil moisture equals the field-moisture capacity in the entire soil column from the soil surface down to the water table. All additional infiltration goes directly into the ground water reservoir. Excepting as it may be removed by evaporation or by transpiration through the vegetative cover, soil moisture remains within the soil. Ground water, on the other hand, is gradually exhausted by outflow to streams or lakes. During a prolonged drought both soil moisture and ground water become severely depleted. When rain comes the infiltration all goes to replenish soil moisture until this is restored to field-moisture capacity.

While actual drought conditions end for most vegetative cover as soon as the soil moisture content rises well above the wilting point, the drought is not completely ended until the soil moisture is restored to field-moisture capacity and sometimes longer. Since moisture to replace transpiration is continually taking its toll out of infiltration, and ground water flow still goes on, it may take a year or several years to restore ground water storage to normal. In the meantime wells are low and stream flow falls off quickly during periods of low precipitation.

While vegetative cover increases evaporation through increased transpiration, on the other hand it

- (a) reduces direct soil-surface evaporation by reducing soil temperature,
- (b) reduces run-off and increases infiltration and soil moisture available for vegetation,
- (c) may increase ground water flow in so far as increased infiltration exceeds the transpiration requirements,

(d) reduces soil erosion and consequent silting of streams by

(1) acting as a binder to the soil

(2) reducing run-off velocities.

Adequate moisture for farming depends as much upon the rate of evaporation as upon the rate of precipitation. It requires almost twice as much water to produce a ton of alfalfa in Texas as in southern Manitoba. Thus the scanty rainfall of the southern prairies is still more scanty in effect when subject to intense evaporation caused by hot dry winds which occur in the months of June and July during years of low precipitation. Considering that over a great portion of the west the agricultural economy is focused upon the conservation of moisture, the selection of a proper vegetative cover is one of primary importance.

Our knowledge of the behaviour of natural vegetation shows that both the growth and reproduction are at their best in the seasons of most favourable moisture conditions. Likewise more can be accomplished by restorative methods in periods of high or moderate rainfall than in periods of low rainfall.

CHAPTER 111

MANITOBA WATERSHEDS

GENERAL

The nature of the problems relating to the use and control of water depends partly upon the physical factors which govern its occurrence and partly upon the uses for which it may be required. The uses of water in any locality depend upon the pursuits or industries which that locality might otherwise support, or in the final analysis upon the resources of the area under consideration.

In Manitoba the physical factors which so largely control the occurrence of surface and underground water supplies are in the main identical with those which determine the uses of water. In the southern portion of the province the comparatively deep soil covering which has favoured agricultural development has also contributed to the remarkably even stream gradients and very nearly complete drainage. As a result there are few lakes or lake-like expanses; rivers have unusually irregular flow characteristics; drought and flood conditions are likely to alternate with remarkable frequency; the soft soils offer very little resistance to erosion and especially when cultivated along the steeper slopes are likely to suffer serious damage; the main streams are likely to occupy fairly deep basins considerably below the general prairie levels. The larger urban centres situated in the agricultural region and the numerous homesteads along the banks of prairie streams and runways introduce pressing problems relative to pollution and sanitation. Increasing populations and industrial development raise problems of domestic, stock-watering and industrial water supply and of parks and recreational facilities.

In the northern and eastern watersheds, on the other hand, the exposed or nearly exposed bed rock has precluded the general use of the area for agriculture and the same geological conditions have contributed to extremely uneven stream gradients, where rivers are likely to take the form of chains of lakes with interconnecting rapids and waterfalls. Stream regimen under these circumstances is relatively even. There is a much narrower range between high and low flows than would occur in prairie rivers; extreme drought or extreme floods are unusual. Where there is any considerable depth of soil, natural forest cover offers a large measure of protection against sheet erosion and a habitat for wild game, fur bearers and bird life. In the main, rapids and waterfalls occur over ledges of bed rock and stream erosion and siltation are reduced to a minimum. The slow eroding bed rock maintains wide differences in elevation between lakes and permits water to be carried through considerable distances in pipes or open channels under gravity. The resources of the area, though tremendous in their aggregate, are generally such that developments are likely to be confined to mining, water power, lumbering, fisheries, the propagation of fur bearers and wildfowl and such processing or servicing industries as may follow in their wake.

The general line of demarcation between the areas discussed as north-eastern and south-western respectively coincides approximately with the south-western boundary of the pre-cambrian shield in Manitoba. This line follows a generally north-westerly direction from the south-eastern corner of the province to intersect the Manitoba-Saskatchewan boundary a few miles north of The Pas. The divergence between the types of water problems becomes wider as the

distance from this line increases. In its general vicinity, particularly for a few miles south and west of this line is the so-called park belt in which hydrologic conditions are less variable with respect both to precipitation and surface supplies than those occurring in the prairie regions to the south-west.

For the purposes of a preliminary report a detailed examination of the various watersheds of the province with their particular characteristics and physical properties would be unwarranted. In most instances sufficient meteorological, hydrological, geological and topographical data are not available upon which to base such examinations even if it were deemed advisable to broaden the scope of this report so as to embrace this phase of the subject. On the other hand a preliminary report, even though it may deduce the fundamental principles and considerations required for a sound appreciation of the problems involved would necessarily lose much if it were restricted entirely to generalities. In order briefly to indicate the practical application of general principles to specific instances, a brief citation of a few representative areas may serve a useful purpose. In the matter of northern and eastern watersheds any specific treatment is limited to the section on water power, the great proportion of which is restricted to the rivers of that area. In the main the other sections have special reference to prairie conditions.

PRAIRIE WATERSHEDS

A large portion of the lands of the first prairie level, lying east of the Manitoba escarpment, is underlain by deep impervious clays which prevent any appreciable amount of deep seepage or percolation. The steep grades of the escarpment comprising the

eastern slopes of the Pembina and Tiger Hills and of the Riding and Duck Mountains cause rapid spring run-off toward the east.

This drainage, in combination with the low infiltration and percolation capacities of the soils and the very gentle slopes of the first prairie level, contributes to chronic spring flooding. A large proportion of the drainage works undertaken in Manitoba is located in this area and was designed to meet the conditions resulting from the factors outlined above.

Occasional local floods are sometimes attributable to frazil and anchor ice. Water at high velocities such as are induced by steeper slopes may remain liquid at temperatures below the normal freezing point. Small ice particles form as the velocities are reduced and these particles adhere to the beds and banks of the streams, gradually forming solid ice, to force the stream upward and over the banks. This type of flooding is usually restricted to small localities but highway and railway crossings may be considerably damaged.

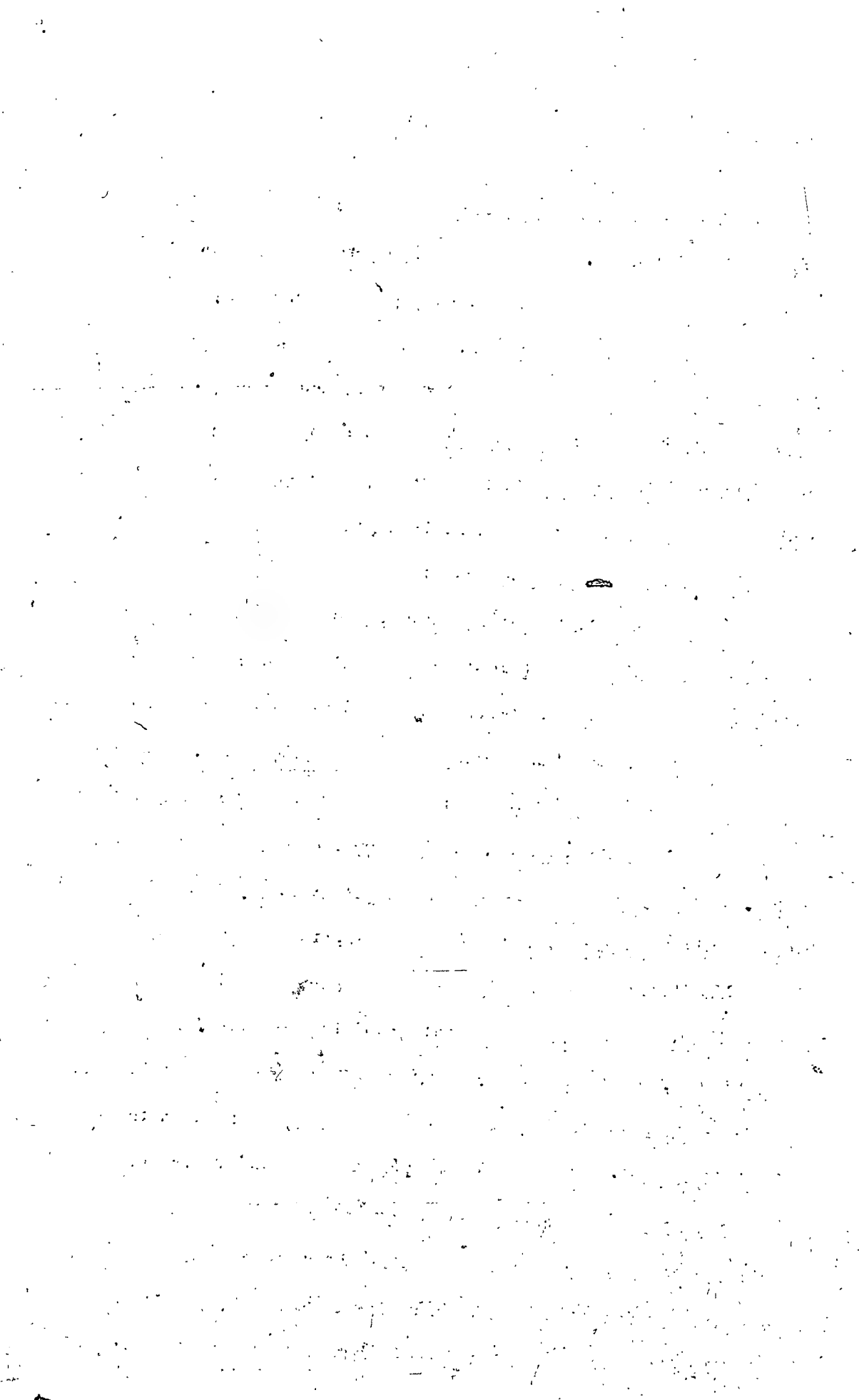
Where the higher run-off velocities occur from the eastern slope of the escarpment are to be found the most serious erosion problems in the province. The damage caused, as is common to erosion in most instances, is twofold. Not only are the eroded slopes seriously damaged but the final deposition of the eroded soils on flatter lands or in stream beds, runways or drainage ditches causes still further damage.

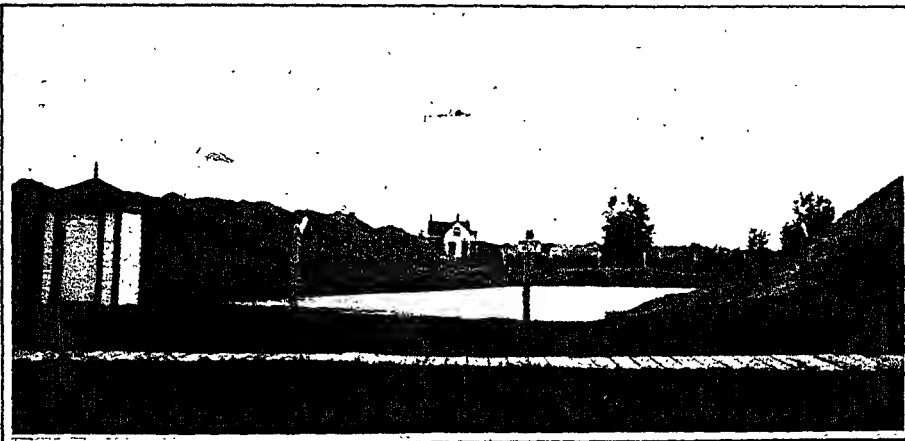
In a large portion of the area under consideration, water supply for domestic and stockwatering purposes has been one of the most vital factors controlling the general development and the degree of prosperity attainable. The wide distances between the

larger rivers, the uneven regimen of the smaller streams and adverse soil and geological conditions with respect to underground water have been formidable obstacles in the development of adequate supplies. Wells to great depths have frequently failed to yield water while other deep wells have tapped saline or otherwise unsuitable sources. The great depths to which it has been necessary to drill, together with the large percentage of failures, have combined to make exorbitant the costs of ground water prospecting in many areas. In some vicinities it has been necessary to haul water considerable distances, and to restrict agricultural development accordingly.

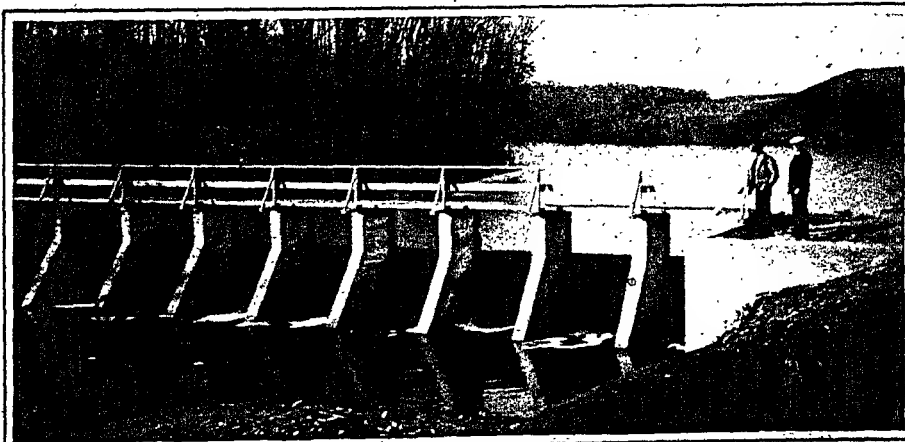
During the recent drought years conditions in many sections of this area have been particularly severe. Inadequate water supplies have limited the amount of livestock that could be raised, in many cases to less than self-sufficing requirements. Comparatively small amounts of water would have saved many small gardens which were otherwise useless. Living conditions, made generally deplorable by drought and depression, were made all but intolerable by almost complete lack of water supplies.

Conditions in many localities have been considerably improved during recent years by the excavation of farm dugouts. These usually comprise excavations, carefully located as to receive the natural run-off from an area deemed sufficient to furnish the necessary supply. Care is also taken that the excavation be made in clay of satisfactory consistency so that seepage losses are reduced to a minimum. Various methods are used to protect the dugouts against excessive evaporation from high winds, from loss of volume through soil drifting or siltation and against pollution





FARM DUGOUT WATER SUPPLY



STOCK WATERING DAM - SOURIS RIVER

erosion is more prevalent. In the extreme south-west corner of the province, however, the run-off from the Turtle Mountains introduces problems similar to those prevalent along the escarpment.

In many sections of this area the problems of farm and community water supply are extremely serious. The lower normal precipitation common to this area is reflected in scantier water supplies. Ground water in many sections is most unreliable.

Deep wells are costly and the probabilities of tapping a satisfactory aquifer have been discouraging to date. In the southern part of the second prairie level in Manitoba farm water supply conditions in a few localities have been considerably improved by the excavation of dugouts and the construction of small dams. It is only by the extension and broadening of this work to the point that every feasible source of water supply has been adequately developed that the agricultural production of the area may be extended, broadened and given the degree of security it requires to support a reasonable standard of life.

In the south-western and generally more arid portions of Manitoba the prosperity and happiness of the populations resident therein depend upon the productivity of agriculture more than upon any other single factor. Experience has shown that the volume and range of agricultural production depend more fundamentally upon water than upon any other of the various conditioning factors. It would appear to follow that the water problem in its various aspects is fundamental to this region and to the province generally and that the maximum degree of prosperity attainable is dependent upon the optimum use of water. It must be acknowledged that there are

1950



definite limits to the control which man may exercise over this problem. There is no practicable method by which precipitation, as such, is likely to be influenced. In very few instances can field crops be economically irrigated, but such water as does occur in any area may be put to varying degrees of usefulness. The dugout and the stockwatering dam are small scale practical illustrations. They and similar projects upon larger scales provide for a broadened base of agricultural income. They provide alternative and supplementary sources of wealth. They would in certain instances assure garden stuffs and some feed. Even in periods of the most severe drought they would lessen the impact by reducing the severity of the first year and by enabling the farmer to make more complete use of the precipitation which presaged the ending. Such scanty precipitation as does occur in even the most severe droughts would be put to greater use.

In the prairie sections east of the escarpment the ideal solution to the several aspects of the water problem would be approached by some means that would enable the normal run-off from the uplands to be retained during the early spring and thence released at non-eroding velocities to protect the steeper slopes against erosion, to reduce the flood hazard on the lower lying lands, to prevent siltation and deterioration of needful drainage works, to improve the regimen of numerous streams and to provide innumerable productive agriculturalists with a vital necessity to production.

In the lands west of the escarpment the ideal is essentially similar. It involves the closest feasible approach to complete water conservation and use. This would comprise the accumulation of normal surface run-off in natural channels or artificial excava-

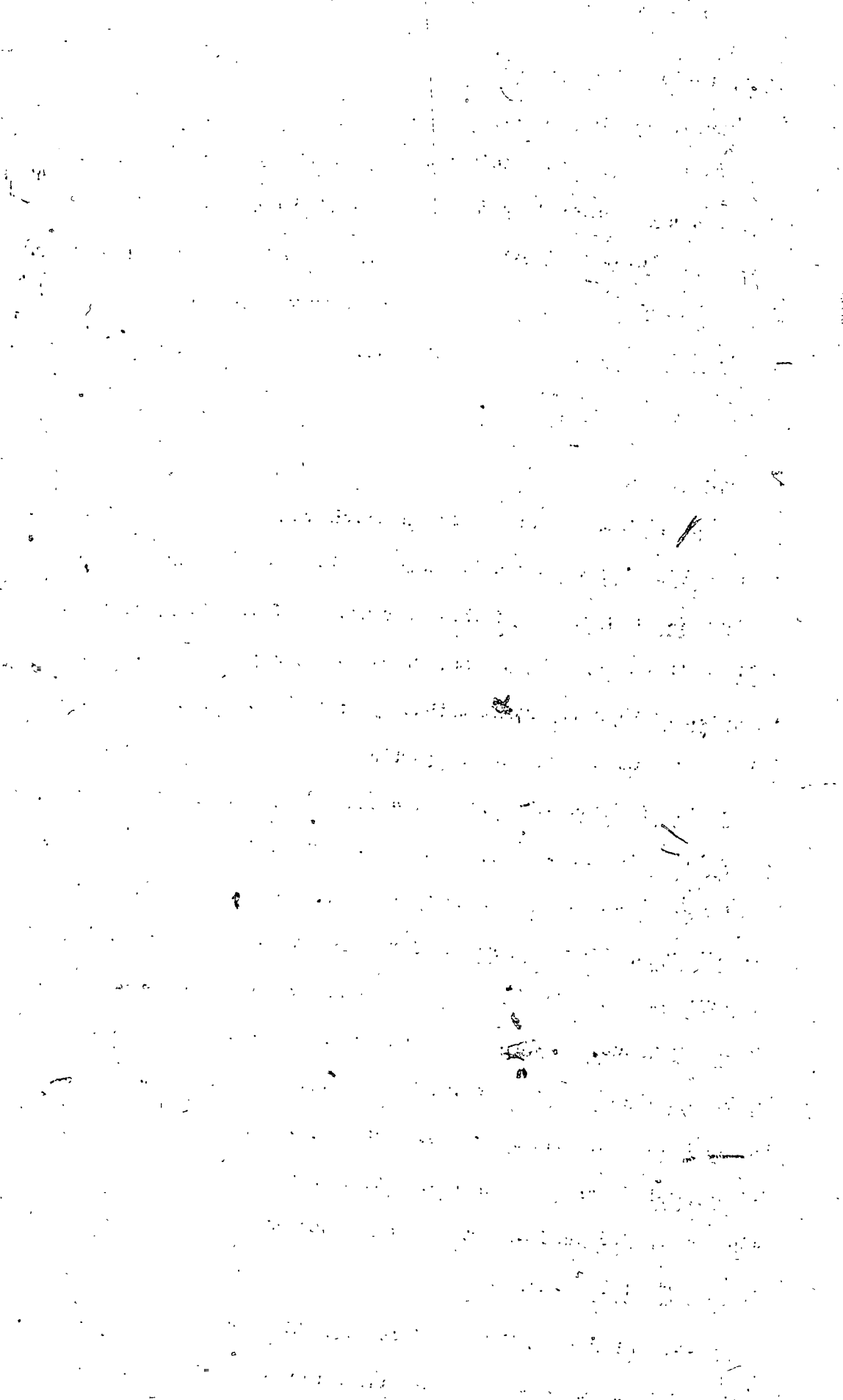
tions, the development of reservoirs, ground water supplies and the improvement in stream regimen.

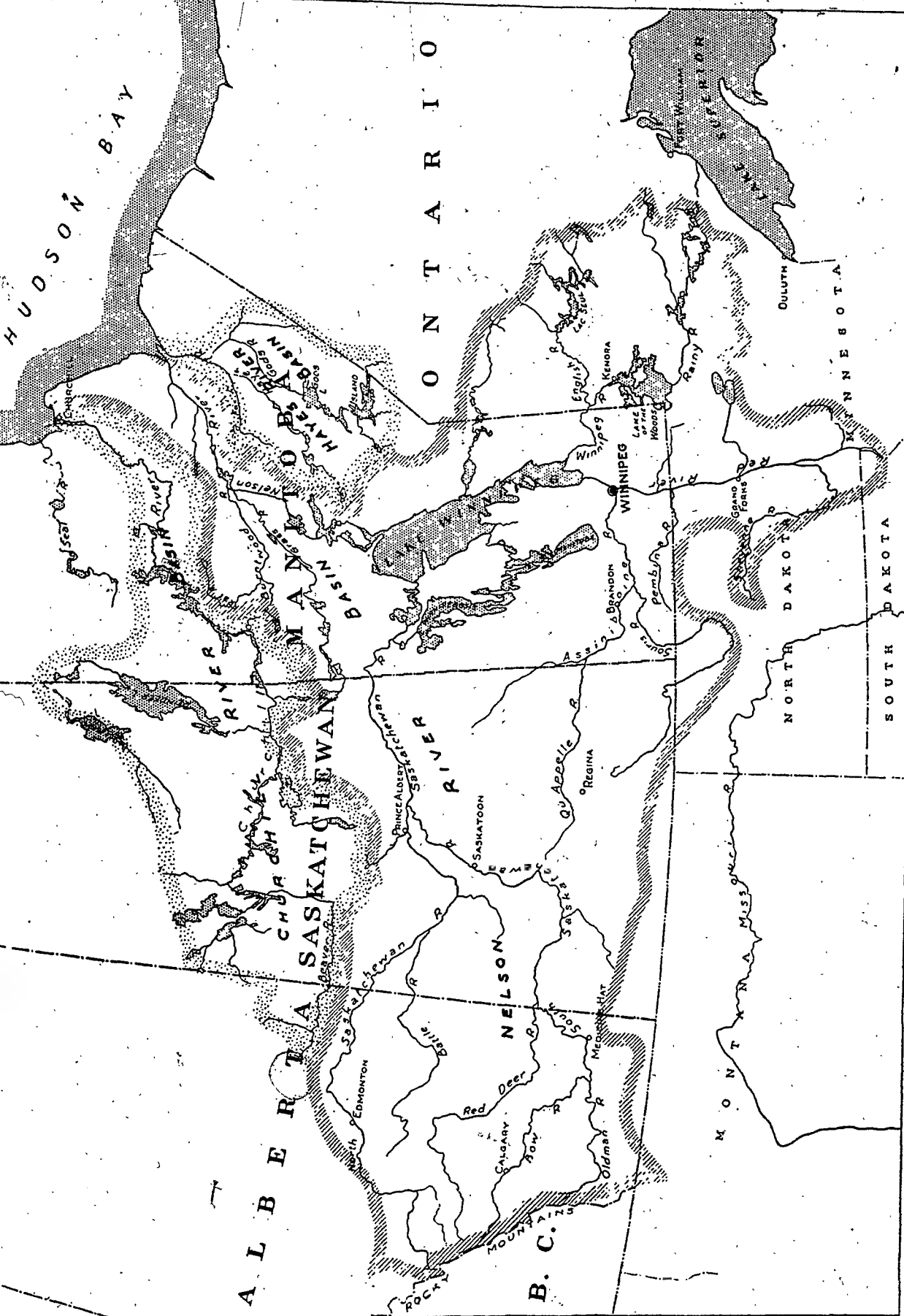
While it is undeniably true that sufficient data are not available upon which to venture a prediction that a close approach to the conservation ideal is feasible, it may be stated with special emphasis that the same lack of essential data should not be interpreted as conclusive evidence that the conservation ideal may not be more closely approached.

PRAIRIE RIVERS

The larger prairie rivers in which Manitoba is interested find their sources or have considerable portions of their drainage areas outside the boundaries of this province. The Red River, with its eastern tributary, the Roseau, rises in the United States. The Pembina, another important tributary of the Red, rises in Manitoba but throughout a considerable portion of its course flows through the State of North Dakota. The Assiniboine, with its tributaries, the Qu'Appelle and Souris, rises in Saskatchewan and flows for considerable distance through that province. The Souris flows across the international boundary and for some distance through the State of North Dakota before entering Manitoba near the south-west corner of the province. The Saskatchewan rises in numerous tributaries along the eastern slope of the Rocky Mountains in Alberta and flows in two main branches, the North and South Saskatchewan respectively, across central Saskatchewan to join at a point a few miles east of Prince Albert and thence easterly into Manitoba a few miles west of The Pas.

The interprovincial and international character of those rivers raises important considerations for this province. The





MAP SHOWING DRAINAGE BASINS
OF MAJOR RIVERS OF MANITOBA

larger areas contributory to these rivers result in their carrying quantities of water far in excess of that contributed by the Manitoba portions of the watersheds. Manitoba is not, however, free to use these rivers as she will. The corollary also holds that this province has vital interests in what uses are made of the waters of these rivers that lie outside the boundaries of Manitoba. The vaguely defined laws and principles with respect to rivers and river use make it particularly important to this province that vital problems be studied prior to likely events. The principle of prior appropriation in water and river use has usually carried some weight in the courts. Prior use has been treated somewhat as prior possession and has frequently been conceded as carrying some rights. It is important that this province determine in advance the most likely local uses of these streams, the uses most likely to be made by communities outside the boundaries of this province, and the likely effects of these, one upon another. It is not meant to suggest that in general the use of the head-waters or upper reaches of these rivers need necessarily prove detrimental to projected uses within this province. Indeed the opposite may frequently be the case. It is, however, distinctly in the interests of all parties concerned that projected uses of the various reaches of any river system be harmonious in their relationship to one another. The recent drought period has given particular impetus to the study of the use of streams in which Manitoba has vital interests. Many of the uses under consideration elsewhere are projected for long periods and may become integral with long term programs. It must be acknowledged that in general it is more feasible to alter an idea than to alter specific plans,

and, in turn, more feasible to alter plans than completed works.

It would appear to follow that the interests of this province require that a careful watch be maintained of happenings elsewhere and that representatives be prepared to consult in these matters. It is worthy of emphasis that such representatives could more adequately serve the interests of this province if they were equipped with sufficient data upon which to base preliminary plans, upon which to determine likely uses and upon which to predict the likely effects of projected works. More weight and influence would be carried by such representatives than if they were forced, through lack of data or preparation, to urge a purely idle "wait and see" policy upon communities in which the water problems are even more urgent and fundamental than those which beset the most hard pressed sections of Manitoba.

The most important group of problems with respect to prairie rivers has a common origin in the extremely uneven flow characteristics or regimen which are associated with these streams and which have been dealt with in an earlier section of this report. The specific problems to which these characteristics give rise are associated with every use of the river and frequently with the uses of large areas of the watershed, particularly those which comprise the lower valleys.

The extremely low flows which have occurred during the later seasons of the recent drought years have in many instances curtailed the use of the river water for agricultural purposes. Railways, creamery plants and other industrial users have been severely handicapped. Many streams that have normally carried some flow throughout

the year have been dry during a considerable portion of the late summer, fall and winter months. Agricultural uses of these streams have necessarily been foregone and great inconvenience and financial loss have inevitably resulted.

Cities and larger communities have suffered deterioration of their domestic and industrial water supply and have been threatened with actual disruption. The poorer quality and increased hardness common to extremely low flows have caused further expense in water treatment and general inconvenience.

Uses that were comparatively innocuous during years of normal flow have become extremely obnoxious during the periods of very low flow that have been so characteristic of the drought years. Sewage and waste disposal are cases in point. General experiences in various sections of the country indicates that the sewage from large cities is usually in the neighborhood of one hundred gallons per capita per day. It is generally found that where river flows are sufficient to dilute this sewage by 10 to 1 the resultant pollution problem is not likely to be serious.

Applying this rough rule of thumb to the case of the Red River at Winnipeg, the most congested centre of population in the province, it will be seen that an estimated population of 300,000 would be expected to add approximately 30,000,000 gallons of sewage per day to the flow of the Red River. According to the proportions set out earlier, reasonable self clarification would require a continuous flow of approximately ten times this volume - 300,000,000 gallons per day or approximately 460 cubic feet per second. The mean river discharge below the juncture with the Assiniboine is approximately ten times the minimum requirement of 460 c.f.s. The Red River alone

at Emerson carried a mean flow of over 500 c.f.s. for February, the normal low month, from 1912 to 1931 inclusive. During September, 1931, this flow dropped to 55 c.f.s and in January, 1935, to 12 c.f.s. The results of these extremely low flows were very soon evident by the condition of the Red River below the Winnipeg sewer outlets, a condition which became increasingly obnoxious with continued low flows.

The condition has lately been rectified with the formation of the Greater Winnipeg Sanitary District and the construction of a modern sewage treatment plant, designed to serve the city and the adjoining municipalities. Manitoba's most serious individual pollution problem is well on the way toward a satisfactory solution.

There are, however, other pollution problems affecting the prairie rivers and streams. While low flows are not the primary cause of these conditions they do, as in the case of the low flows on the Red River cited above, seriously accentuate the condition and impair stream use and public health.

While the recent drought period has emphasized the dangers and general inconvenience contingent upon extremely low river flows, it is necessary to bear in mind that there are corresponding dangers incident upon the other extreme. River flooding has caused considerable damage in Manitoba, particularly along the Assiniboine and Red Rivers.

Severe floods occurred in the Assiniboine valley in 1913, 1916, 1922 and 1923. Floods of even greater intensity than those of which there is precise record are reported to have occurred in 1882 and at various times prior to that date. Floods of somewhat lesser intensity occurred in 1925, 1927 and 1928. The flood of May 1922 had carried the highest discharges recorded at Brandon during the

period of record which then extended from 1912 to 1922. The following May a still higher crest was recorded at this point and the peak discharge of 23,000 cubic feet per second has remained the maximum for the period 1912 to date.

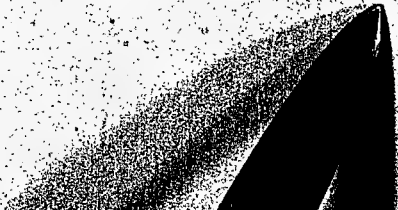
The 1922 flood was from many aspects the most severe during the period of record. The high flood stages were maintained for an unusually long duration and the stage was only slightly lower than the 1923 crest. The flood of 1922 was caused indirectly by heavy precipitation during September, October and November of 1921, which thoroughly saturated the land and filled lakes and sloughs prior to freeze-up. This was followed by heavy precipitation on the upper watershed during the early spring. The spring break-up which occurred early in April was followed by heavy snow and rain and comparatively high temperatures. Heavy rains which continued on into May were partly responsible for the extended period during which the flood prevailed. The interrelationship of the direct and indirect causes together with the general effect are set out clearly in the diagram on the following page.

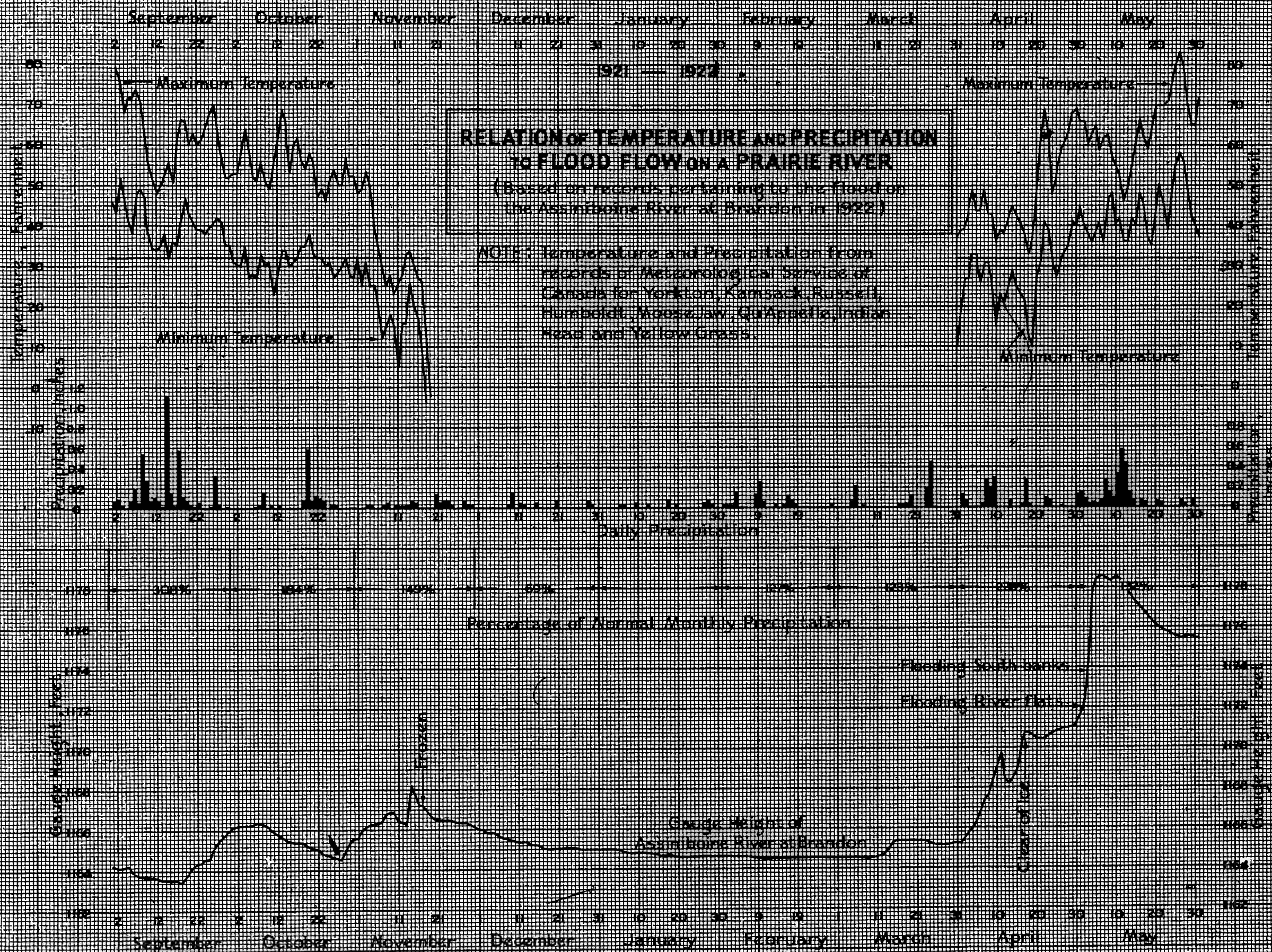
It is estimated that approximately 35,000 acres of cultivated land were flooded, approximately one-half of which had been seeded prior to inundation. Throughout the valley a large number of roads and bridge approaches were damaged. The sewer outlet at Portage la Prairie required costly repairs due to the river having cut for itself a different channel. In the city of Brandon the "flats" were almost entirely inundated and approximately two hundred homes were flooded up to the ground floor level.

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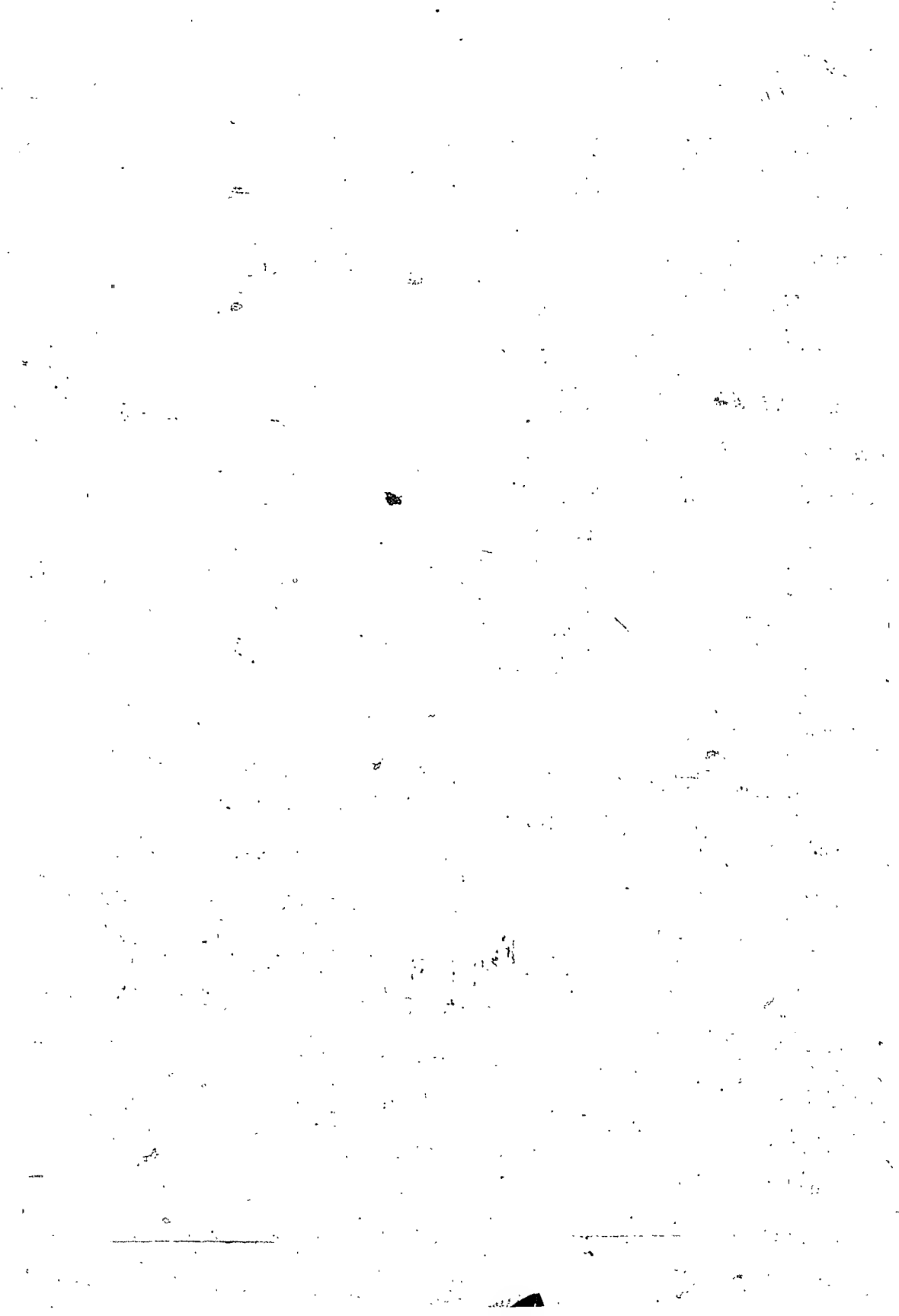


The history of floods on the Red River is much more complete and extensive than that available for the Assiniboine. Records of a fairly reliable nature are available for several floods which occurred in the lower valley of the Red River since 1826. The years during which exceptionally high water occurred in the vicinity of Greater Winnipeg, together with elevations above mean sea level to which the flood crests are estimated to have reached are as follows:

1916	-	752	ft.	
1904	-	754	"	
1897	-	753	"	
1882	-	756	"	
1861	-	763	"	to 764 ft.
1852	-	765	"	to 768 "
1826	-	767	"	to 769 "

The natural ground level on the west side of the river in the vicinity of the city of Winnipeg ranges from 754 ft. to 764 ft., probably averaging 761 ft. throughout the greater portion of Winnipeg. On the east side of the river elevations are considerably lower, sufficiently low that a considerable part of Norwood and St. Boniface was flooded during the 1916 high water when elevations of 752 ft. were reached by the flood waters. It will be noted that the floods of 1826, 1852 and 1861 reached elevations considerably above general city level and that a recurrence of these extreme conditions would inundate the greater portion of the city to depths varying from five to fifteen feet.

The havoc wrought by floods of these proportions in modern large cities defies description. The conditions are not those of a placid lake but rather of a torrential river. High velocities swirl and eddy amongst buildings, eroding and undercutting foundations. Buildings collapse, pavements are displaced, sewers are flooded,



water mains burst and water supply is disrupted. Power systems are damaged and the power is cut off. The destruction of railway and highway grades and bridges disrupts traffic, and communications by road, rail and wire are severed. In flat valley lands the great distances to higher refuges make escape difficult. Silt and debris are deposited wherever the waters reach. Damaged oil storage tanks may pour huge quantities of highly inflammable material on to the flood waters. A stray spark or live coal may ignite the floating oil to complete a spectacle of utter destruction.

There is every reason to believe that the severe floods of the Red River were due to a combination of factors similar to those represented on the preceding page. Heavy fall rains, an early freeze-up, a winter of heavy snowfall and continuously low temperatures persisting until late in March, followed by consistently high temperatures in early April are the essential factors inducing flood conditions. Heavy April rains may extend the flood period but are unlikely in themselves to cause extreme stages.

There is no evidence, either in the brief history of the Red River nor in the thousand year records of streams elsewhere that these controlling factors are any less likely to occur in the future than they were in the past. Nothing that has been done nor that can be done offers any promise of reducing the likelihood of heavy fall rains, of early winters, of heavy snows, of late springs, nor of relatively high April temperatures. The fact that this combination of circumstances has recurred three times in less than a century forms a preponderance of evidence that they are likely to recur.

Such land clearing, cultivation, artificial drainage, bridge and pier construction and similar alterations as have been made in the watershed may tend to relieve some local condition but their net effect is more likely to increase extreme flood stages rather than to lower them.

The task of providing complete protection to the Red River valley would be stupendous. The extent of the present hazard, however, is indicated by the brief history of this river, together with certain knowledge of the extensive damage floods must cause once they occur in populous communities would indicate that these problems should be receiving continued attention. From one aspect floods on prairie rivers are less dangerous to human life than those which occur in river valleys of the more humid regions. There, extreme floods frequently result from excessive storms which may occur with a minimum warning. Floods on prairie rivers on the other hand give considerable warning of their approach, provided the scientific and data collecting agencies which alone can perceive that warning are maintained. Heavy fall rains raise the first faint warning. An early freeze-up denotes a slightly increased flood hazard. Heavy winter snows and continued cold weather over the watershed indicate a still closer approach of flood danger. A late spring with continued snowfall and cold weather in March super-added to the other conditions should be cause for preliminary organization of flood defence and relief. Sudden high April or late March temperatures would sound a final warning.

The Saskatchewan River drains an area of approximately 150,000 square miles, a drainage basin three-fifths as large as the province of Manitoba. The great proportion of the water carried by this river

originates from the melting snows along the eastern slopes of the Rocky Mountains. The fact that this source continues actively to supply the river on into midsummer, together with the fact that the water traverses such tremendous distances accounts for the fact that high water on the Saskatchewan occurs during the late summer, at a time when other prairie streams are approaching their lower stages. During some years two distinct peaks are noted in the Saskatchewan River flow, particularly in the lower reaches. One may occur during the early spring, the result of local thaws; the other usually occurs during the late summer, the result of melting mountain snows.

Except for these peculiar characteristics the regimen of the Saskatchewan is similar to that of the typical prairie stream. The range between high and low flows is tremendous. During the period of record at The Pas which extends from 1913 to date, extremes varying from less than 1800 to more than 103,000 cubic feet per second have occurred. The average July flow is between twelve and thirteen times as great as the average February flow. The maximum monthly average flow on record occurred in August 1916 when this figure reached to almost 95,000 cubic feet per second. The lowest monthly average of 1900 cubic feet per second occurred in January 1930.

The fall in the river between Cedar Lake and Lake Winnipeg is approximately 120 feet. If the river maintained a uniform average flow over this reach it would be possible to develop approximately 250,000 continuous horsepower but, due to the extreme variation in flow, only 15,000 to 20,000 horsepower would be available during some months.

This wide variation in flow is the most formidable obstacle to the development of the Manitoba reaches of the Saskatchewan River for power purposes. The Dauphin River Power Scheme is a practicable project designed to circumvent this obstacle. This scheme proposes the diversion of the Saskatchewan River into Lake Winnipegosis and Lake Manitoba and thence by an improved Dauphin River channel to Lake Winnipeg. The central feature of the scheme is the proposal to store the high flows in Lake Winnipegosis and Lake Manitoba whence they would be drawn by the Dauphin River channel in a controlled and uniform regimen. The fundamental purpose of the scheme is analagous to a domestic cistern situated in the basement of a home for the purpose of collecting water during rainy seasons in order to supply a uniform demand throughout the year.

The portion of the Saskatchewan River watershed which lies between the Manitoba-Saskatchewan boundary and Cedar Lake is frequently referred to as the Saskatchewan River delta or flood plain. This area comprises approximately one and one-half million acres. The terrain of the delta is extremely flat. In only rare instances is there a promontory that rises more than a few feet above the level of the surrounding lands. The area is dotted with shallow lakes and ponds of indefinite shore lines which gradually merge into the surrounding marsh lands.

The delta has been formed, probably by sedimentation in an ancient lake and later by the periodic overflow of the river and the resulting deposition of silt. Siltation has taken place in the stream beds and along the banks until, in many instances, the river channel has become elevated above the level of the surrounding lands. In general the banks of the main stream channels are the

highest points in the area. In flood years the river spills over the banks to inundate the greater portion of the delta. River channels and stream beds are most unstable in the area and new channels have been cut and old ones silted up, frequently within living memory.

The lands of the Saskatchewan River delta have been under periodic examination by various governments since 1884. Investigations were conducted between 1912 and 1923 by engineers of the Federal Department of the Interior to determine the feasibility of reclamation for agricultural purposes. The lands were found, upon close examination, to be fertile and suitable for grass and grain crops. Many parts of the area were found to be irrigable from the Saskatchewan River during certain months, usually July and August, of normal years. It was found, however, that reclamation would be feasible only under one or two gigantic schemes. The drainage or reclamation of small areas of the delta was found to be entirely impracticable due to the ever present danger of excessive floods that could be adequately guarded against only by the larger projects. The costs of the larger schemes were variously estimated as between \$8.00 and \$15.00 per acre reclaimed, and these upon a basis of something in the neighborhood of a million acres. The various investigators concluded that the costs involved were not justifiable at the dates of their reports. They were unanimous, however, in their confidence that the schemes would some day be proceeded with.

The earliest available reports of the Saskatchewan River delta indicate that the marsh lands of this area had produced a rich annual harvest of muskrat pelts. Early estimates indicate that

during some years between five hundred thousand and a million pelts were taken. During other years the catch had been very much less, but the extreme low periods had been of very short duration.

Within the past two decades, however, the fur production has fallen to meagre proportions. Hardship and famine became more common than bountiful fur yields. The causes of the decline were carefully investigated and are now believed to be associated with numerous conditions. Uneconomic trapping practices had played a part, several diseases to which the muskrats are prone had taken periodic toll and water levels on the marsh had had an important influence. During periods of high water the marshes had been flooded to considerable depth. This had resulted in ample feed and protection against winter freezing. During periods of low water there had been comparatively little water in the marshes, feed was scarce and the lakes and ponds had frozen to the bottom. Such seasons had made disastrous inroads on the muskrat population and had caused widespread hardship amongst those who depended largely upon muskrat trapping as a source of livelihood.

Investigations and experiments since 1930 have revealed that in most years there is sufficient flow in the various channels to flood the marshes to considerable depth if the high banks had allowed the water to leave the channels. Some parts of the marsh area were separated from the river channels by particularly high banks and had been flooded only in years of exceptionally high water. Other areas were flooded during parts of most summers by ebb and flow channels, but were drained during the late fall due to the drop in river levels.

Practical experimentation since 1930 has demonstrated that by conservation methods which involve the strict control of trapping and the control of water levels by the excavation of canals through the higher banks, damming and dyking of the normal outlets and the construction of control dams in the main canals, the marsh lands of the delta may be made to equal and probably to exceed their former productiveness. Where these methods have been followed the muskrat population has been found to increase between five and ten-fold per year.

Contrary to what might appear to be the case at first glance, rehabilitation of the marsh lands of the delta for muskrat purposes is largely compatible with their later use for agricultural purposes. The canals necessary to flood the lands for muskrat rehabilitation will be necessary under the drainage scheme to carry the local runoff to the pumping stations. The bank improvements and dykes are located essentially where the later large flood protection levees would be required. Some of the control gates may later serve for the control of irrigation and drainage canals. While the inundation of the lands may be detrimental, the anticipated siltation in the lower basins may ultimately prove beneficial to agricultural use.

While there would appear to be a harmonious relationship between muskrat rehabilitation and reclamation for agricultural purposes when considered in terms of a comparatively long period, it is not meant to suggest that these two purposes can be served simultaneously in various small areas of the delta nor that one of these uses may lead gradually into the other. The physical characteristics of the area are such that it must be treated in certain large

units for either type of development. One of the largest of these natural units extends from a short distance west of The Pas across the interprovincial boundary and several miles into the province of Saskatchewan. If any development of this particular area is to be undertaken, no matter to what purpose, it is essential that the plans of the two interested governments be completely co-ordinated. The development of the Manitoba portions of this area would be compatible only with similar uses of the area lying in Saskatchewan and vice versa.

It is worthy of note that in the preceding outline of the Manitoba reaches of the Saskatchewan River the conditions reviewed were those that have prevailed and would be likely to prevail under a state of natural river flow. Any major alteration in that natural flow would necessarily alter those essential conditions. For instance any appreciable diminution of the higher flows might adversely affect muskrat rehabilitation in Manitoba and most certainly reduce the area that could be so developed. On the other hand any dependable reduction in the peak flood flows that might be expected would lower the costs of reclamation for agriculture. An appreciable reduction in total flow would cause a corresponding reduction in the power available for development by the Dauphin River Scheme and would also cause a reduction in the amount of power available on the Nelson River. On the other hand, if by some form of regulation in the upper reaches, the low flows could be appreciably increased, the chief obstacles to the development of other possible water power sites might be thereby surmounted.

Whether the interests of Manitoba would be beneficially or adversely affected by developments on the upper reaches of the Saskatchewan would depend upon the nature of those developments

together with the uses which Manitoba intended to make of the portion of the river and of the watershed within this province. Conversely the uses to which these could be most advantageously devoted may depend upon the developments on the upper reaches. While it is not the purpose of this report to determine finally what those uses are to be, nor in what manner the best interests of this province are ultimately to be served, it is important that due emphasis be placed upon the fact that Manitoba has vital interests in the Saskatchewan River west of the Manitoba boundary and that these can be at present best protected by close study of possible and probable uses here and elsewhere, and by consultation and collaboration with those who contemplate developments on the upper reaches.

RIVERS OF EASTERN AND NORTHERN MANITOBA

The Nelson River system, which has a total drainage area of some 450,000 square miles, includes about three-fifths of the area of the province of Manitoba; the remaining areas being drained by the Churchill and Hayes Rivers and several smaller coastal streams, all of which drain into Hudson Bay. The rivers and streams of eastern and northern Manitoba lie almost entirely within the Laurentian Plateau, the surface of which is, in general, rough and hilly although the hills are of no great elevation above the surrounding country. It is mostly a rocky formation containing innumerable lakes, muskegs and swamps together with some areas of glacial clay and supports a good forest growth. The rivers may be described generally as a series of rock bound basins connected by short narrow channels containing rapids or falls. It is on those rivers that the important

power sites of the province are to be found. The entire region from the Winnipeg River north is not suitable for extensive agricultural development. Its development will most likely be associated with mining, lumbering, water power, fisheries, fur bearers and such processing or servicing industries as may follow the development of these basic resources.

The major rivers of this region are the Winnipeg, the Berens, the Pigeon, the Hayes, the Nelson, the Grass, the Burntwood and the Churchill. The most important of the power rivers of the province, from the standpoint of present utility, is the Winnipeg River which supplies the greater part of the power at present being used in the province.

The Winnipeg River drains an area of 53,500 square miles of which 37,900 square miles is in Ontario, 11,000 square miles in Minnesota and 4,600 square miles in Manitoba. The river heads in two main branches known as the Rainy and English Rivers, respectively. The Rainy River discharges into the Lake of the Woods and it is from this lake the Winnipeg River proper flows northward to where it is joined by the English River a few miles east of the Manitoba-Ontario boundary and thence eastward to Lake Winnipeg.

While the greater part of the drainage basin lies outside the province the most important power reach of the river is in Manitoba. On the other hand the storage reservoirs utilized for the regulation of the river flow are in Ontario and Minnesota. The river basin is, therefore, both interprovincial and international in character, a factor that was kept constantly in mind when planning the most efficient utilization of the power resources of the river. To attain this objective it was early realized that some regulation of the

stream flow was necessary and by friendly negotiations and co-operation with the province of Ontario, and by a reference to the International Joint Commission, followed by a treaty between Canada and the United States, storage has now been provided in the Lake of the Woods and on the English River in Lac Seul.

As there were many interests involved in the above mentioned procedure such as forestry, fishing, navigation, agriculture, water supply, summer resorts and power, this illustrates the need and value of a far sighted policy and the need of careful investigation and the collection of the necessary data pertaining to all factors in order to plan the greatest utilization of the streams and lakes for all purposes.

As a result of this planning and the successful attainment of the objectives desired, not only have the interests outside the province benefited but the power resources of the river in Manitoba have been increased assuring a more uniform production of power which has been a most important factor in the industrial development within the province.

The Nelson River flowing from the north end of Lake Winnipeg drops from an elevation of 712 feet to sea level at Hudson Bay in a distance of 430 miles. Remarkable natural regulation of the flow combined with the large head available makes this river one of the most important in the west as a potential source of power.

Situated almost in the centre of a district rich in forest and mineral resources this river with its abundance of cheap power is the key to the utilization of these resources and, with the advent of further improvements in the transmission of power and increased

markets in the southern part of the province, will prove a valuable source of additional power to these markets when present sources have been fully utilized. Up to the present the demand for power has not been sufficient to warrant development on this river.

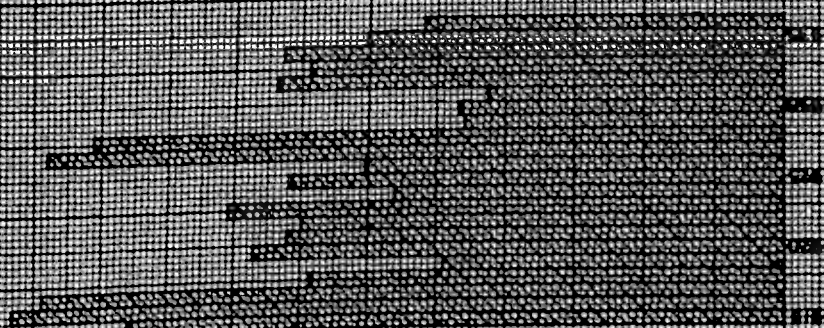
The Churchill River has its source in the province of Alberta and flows eastward across north central Saskatchewan and northern Manitoba, finally discharging into the Hudson Bay at Fort Churchill. This river, probably the second largest river flowing through Manitoba, is a rock bound series of large lake expanses with connecting channels and rock barriers forming numerous rapids and falls. This river drains an area of approximately 115,000 square miles of which some 35,000 square miles is in Manitoba. Its main tributaries are the Reindeer River, draining Reindeer Lake, the Montreal River draining Lac la Ronge and the Beaver River.

The territory in Manitoba drained by this river has not been explored to any extent. There are no developments on the river, other than fur trading posts and the harbour at Port Churchill and there is very little data available regarding the resources of this region.

In Saskatchewan, the Churchill River Power Company have constructed a large hydro-electric power plant at Island Falls with a present installation of 63,500 horse-power and an ultimate capacity of 103,000 horse-power. This plant supplies the power to operate the Hudson Bay Mining & Smelting Company's plant at Flin Flon and also that of the Sherritt-Gordon Mines Limited at Sherridon.

CHART SHOWING TOTAL ANNUAL FLOW

WINNIPESAU, SASKATCHEWAN & ASSINIBOINE RIVERS
(1961-1965)



WINNIPESAU
(Laurelton Stream)
at Slave Falls
Dr Area 48,800 Sq. Miles



SASKATCHEWAN
(Moosehead Stream)
at Fort Mac
Dr Area 148,000 Sq. Miles



ASSINIBOINE
(Typical Prairie Stream)
at Regina
Dr Area 62,400 Sq. Miles

CHART SHOWING
ANNUAL RUN-OFF OVER DRAINAGE AREA
OF
WINNIPEG, SASKATCHEWAN & ASSINIBOIE RIVERS
(1951-1956 - 1961)

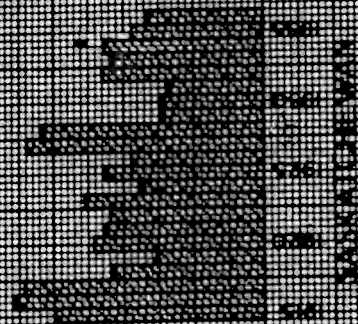
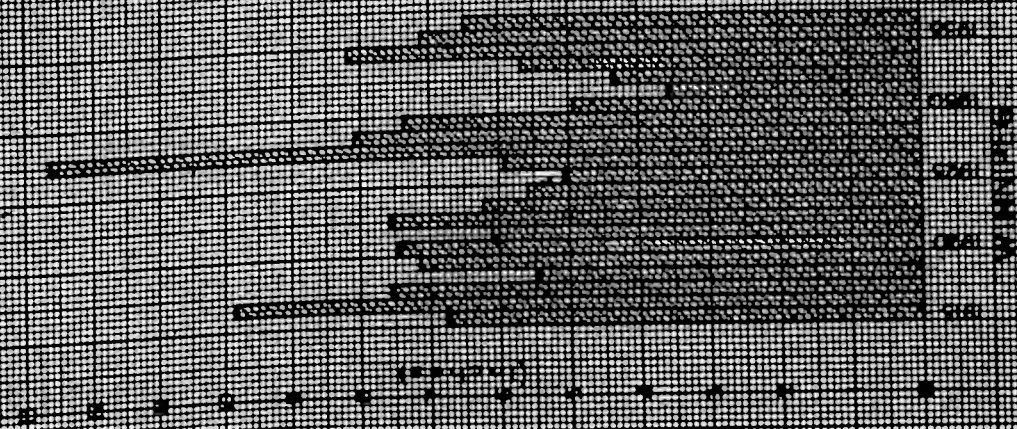


CHART SHOWING COMPARATIVE MONTHLY DISCHARGE OF WINNIPEG, SASKATCHEWAN & ASSINIBOINE RIVERS

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CHAPTER IVUSE AND CONTROL OF WATER RESOURCES

All fresh water that is available for use has occurred at some time as precipitation. The chief forms in which water is available are as soil water, ground water and surface water. There is a constant interchange between these various reservoirs; each is by precipitation or infiltration or percolation being constantly replenished and each is, by run-off and evaporation, being constantly diminished.

SOIL WATER

The chief use of soil water, except insofar as it tends to stabilize ground water and surface water conditions, lies in the vegetative productivity that it gives to the soil. Man can control soil water to some extent by conserving its use for vegetative purposes; that is, by agricultural and forestry practices he may increase the amount or quality of vegetative matter produced during the passage of any amount of moisture from the soil into the atmosphere. This involves supplanting, wherever feasible, the more idle process of soil surface evaporation by the more beneficial process of transpiration. A certain large percentage of soil water will escape annually into the atmosphere. It is, therefore, primarily the task of the agriculturalist and the forester to see to it that this water, in its inevitable passage from soil to atmosphere, nurtures the maximum of beneficial vegetation.

GROUND WATER

Hydrologically one of the most important aspects of ground water is that it frequently controls the most crucially important characteristics of rivers and streams, namely, low water flow. If the water

table reaches an elevation above that of the stream beds, some seepage usually takes place, but the lower the stream stage the higher is the hydrostatic head and the greater the ground water discharge. If, on the other hand, the ground water table is below the stream bed elevation, some part of the channel flow usually percolates into the ground water reservoir. If the ground water table extends to near the surface, soil moisture may be replenished through capillary action and when the water table is within reach of the surface, some deep rooted plants may penetrate to the ground water table and draw their supplies directly from this source.

Most ground water sources occur as nearly horizontal beds of pervious sands or gravels, usually alternating with clays, shales or other impervious strata. Water flows under the influence of gravity along the dip of the water horizon or aquifer. The source from which such an aquifer is replenished by precipitation or surface water may be at the point where the water bearing stratum reaches the ground surface or at some point where the upper impervious strata are intersected by porous materials. In general, the deeper it is from any point on the surface to any aquifer, the greater is the distance to the point where the aquifer is replenished. For this reason the supply of water available from a deep well is likely to be more constant (though not necessarily greater) than from a shallow well.

Wells, tapping ground water, are the most common artificially improved sources of water supply. It is estimated that approximately half the people on this continent are dependent upon this source. Next to the soil, ground water is a dominant element in the success of agricultural enterprise because of its intimate relation to the value and

use of farm land and the comfort and happiness of farm life. From the agricultural standpoint, the supply of well water of satisfactory quality has been one of the controlling factors as to the type of farming that can be pursued. One of the most serious aspects of the recent drought has been the lowering of the ground water table throughout many parts of the west; a condition which has resulted in a serious reduction in stream flow and in the drying up of wells and the consequent disappearance of what had been the most general source of water supply.

The uses to which ground water may be put depend chiefly upon the quantity and quality available and their dependability. These, in turn, depend chiefly upon the geologic and hydrologic conditions which govern its occurrence. Due to the lack of sufficient data in many areas it is particularly difficult to determine where and at what depth water is available and the quality, quantity and rate of replenishment of any ground water reservoir. The lack of hydrologic and geologic data with respect to ground water supplies makes it difficult to determine to what extent the ground water table is being lowered by excessive pumpage or drainage and to what extent this phenomenon is attributable to insufficient precipitation.

The quality of any ground water supply is usually governed by the amount of organic or mineral matter which is in suspension or solution. In general the passage of water through soil has a tendency to filter out any organic matter. Since water from deep wells has usually travelled further through the soil, it usually contains less organic matter than is likely to be found in either surface water or water from shallow wells. Mineral matter, on the other hand, is usually



dissolved by water from the rock and soil particles with which it comes in contact. Consequently, water from deep wells, having travelled further through soils, is likely to contain more mineral matter in solution than would be found in water from shallower sources. Hence, while ground water from deep wells is likely to contain less organic matter, it is more likely to have high degrees of hardness or salinity than would be commonly found in water from shallow wells or surface sources.

Each of the various uses of water imposes certain conditions as to quality. If the economic need is sufficient, the quality of water can frequently be improved by treatment processes. Hardness can be reduced and organic pollution nullified. The extent to which these processes are feasible depends jointly upon their costs and the urgency of the need. In general the cost of softening depends upon the degree of hardness and the type of mineral salts in solution. The use of either softening or purification processes is usually limited to water for industrial or domestic purposes.

While there would appear to be very definite limitations as to the extent to which man can increase the supplies or improve the quality of ground waters, there are numerous ways through which the quality and the continuous best use may be better protected. Certain human actions and practices may have a deleterious effect upon the quality of ground water supplies. Poorly located or inadequately protected wells may become a source of ground water pollution. Contaminated surface water may enter a ground water supply directly by draining into or around wells. For this reason wells should be located away from barns, outhouses or other sources of contamination and the cribbing or casing should be so arranged as to prevent seepage of surface waters directly into wells. Improper disposal of manure, garbage or other contaminated materials may result in the contamination of ground water supplies. The proper

disposal of crank-case oil and other industrial wastes introduces important problems, particularly where water from shallow wells is in general use.

Deep wells are frequently drilled through several aquifers or water horizons. If such wells are inadequately protected or cased, water from the surface may find its way directly into any or all of these, and water from one aquifer may pass, through or around the wells, into other aquifer. Not only are ground waters thus polluted by surface waters, but water of high degrees of hardness or salinity may pass from one aquifer into another, reducing the usefulness of other large reservoirs, unless proper protective measures are taken. The cold water from the lower horizons is sometimes used for air-conditioning purposes. Such water may have a high salt content and particular care is required that this water may not enter other aquifers of better quality. The proper disposal of such salt water after use for air conditioning or other purposes also requires careful handling in order to prevent damage to other supplies or sources.

The position of the water table and the amount of water in the upper soil layers are important from other aspects than vegetation and water supply. These conditions have important relationships to the physical characteristics of soils, particularly their bearing capacities and behaviour under frost action. Periodic changes in the water content of soils cause periodic shrinking and swelling. The water content of soils and variations in the same have an important bearing on foundation conditions and these, in turn, affect construction and maintenance costs of highway and railway sub-grades, pavements and buildings. The water content of the

shallower soils underlying large cities is particularly likely to suffer fairly constant diminution. This arises out of the fact that appreciable proportions of the surface areas are covered by roofs, pavements and other impervious materials which appreciably reduce the amount of water absorbed by the underlying soils. Other factors influence this condition but, in general, the resultant problems, while largely caused by water conditions, must find their solution in design and construction methods which make adequate allowance for likely variations and trends.

In general, the proper handling of ground water supplies in Manitoba can advance along two closely related lines. The first involves the elimination or control of whatever wasteful or harmful practices are known to exist. The second involves the earnest pursuit of accurate and adequate data relating to the quantity, quality, rates of replenishment and dependability of available supplies. With the proper correlation and interpretation of these data, more direct and effective measures of control may suggest themselves. Drainage control, flood spreading, snow control, drainage into deep wells and other systems of artificial ground water recharge have been practised with considerable success when sufficient data were available from which to determine subsurface conditions.

SURFACE WATER

It is in its occurrence on the surface, in lakes, streams, ponds and marshes that water is most easily measured and examined. Both quantity and quality are thus more readily discernible than in the case of ground water. In general, the uses of surface water

include practically all uses of water with but few possible exceptions. In practice the suitability of surface water supplies for any use whatsoever is conditioned by the quantity and quality available, the dependability of these characteristics and by the location of the supplies with respect to the need. Important uses of water differ to a marked extent in their relative urgency of need and while water for one purpose may be easily accessible, for another it may be entirely beyond serious consideration. For practical purposes, any community is not so much concerned with the actual amount of fresh water within any area, as with the amount which is economically accessible for various purposes. The accessibility of any source of surface water supply depends not only upon the distance to the source but upon the relative elevations, the intermediate terrain, temperature conditions and transport facilities. The extent to which practical difficulties can be encountered and overcome in the development of surface water supplies depends upon the quantities required, the purpose for which it is to be used and the urgency of the need. When required in small quantities water may be economically inaccessible at a short distance from the site of demand but when quantities required are large, as in the case of large cities, distances up to hundreds of miles may be within the range of economic feasibility.

The chief characteristics of a satisfactory supply of surface water for domestic purposes are that the supply be adequate to provide the required amounts continuously; that the water be free from organic pollution, disagreeable tastes and odours, excessive hardness and salinity; or that the supply be such that by treatment,

protection or other development, sufficient water of acceptable quality may be delivered to the point of use at a reasonable cost.

Particular difficulty frequently attaches to the problems of securing satisfactory surface water for domestic supplies in small communities or for farm homes. Both treatment and delivery costs are likely to be excessive where only small quantities are dealt with. When purification costs are likely to be high, the necessity of these processes may frequently be eliminated by adopting such protective measures as will keep the supply free from contamination.

One of the most important uses of water, particularly in rural districts is for stock watering. Where such communities are largely dependent upon surface supplies the number of livestock and consequently an appreciable proportion of the farm income may be dependent upon the proper handling and conservation of surface water. It is essential that such supplies be continuously available and in an arid or semi-arid locality the problems involved become not only more difficult, but also more urgent.

Where ground water supplies are inadequate to provide the complete requirements for stock watering purposes, surface sources may be used to supplement the ground water supply. Under these circumstances the supplementary surface supplies would be used whenever available and especially during the summer season when the evaporation from the free water surface is likely to be high.

In those localities where the supply of ground water is inadequate or the quality unsatisfactory it may be necessary to use the same surface sources for both domestic and stock watering purposes.

If the expense of purifying the domestic requirements is not to be incurred it is necessary to take particular precautions in protecting the water supply against pollution.

For several reasons irrigation is unlikely to have any wide application in Manitoba. The fact that even in years of normal precipitation the run-off from the prairie streams in the neighborhood of 2% of precipitation is a clear indication of the limits naturally imposed upon large scale irrigation. The use of all prairie run-off in normal years, if considered in terms of the contributing area, would be equivalent to approximately three-tenths of an inch of rain during the growing season. Since there are only extremely limited storage facilities available, this amount must be further reduced by that proportion of the run-off which is carried away in other periods than the growing season. This would further reduce the precipitation equivalent to approximately one-tenth of an inch in normal years. During exceptionally dry years, when the need for additional moisture is particularly great, the quantities available are appreciably less.

The topography of any area has a most important bearing on the feasibility of irrigation. In general those areas which can be most cheaply irrigated lie at elevations lower than the source of the water. Under these circumstances the water flows under gravity to the site of demand. Only in very few instances in Manitoba do these conditions obtain; generally the opposite is the case and pumping becomes necessary and imposes a heavy financial burden upon any such project usually restricting the application to comparatively high value crops.

While extensive irrigation appears to be uneconomic or even impossible in Manitoba, there are, however, numerous instances where individuals and communities may employ small scale irrigation to good advantage to irrigate small areas for vegetables, fruit and fodder crops, thereby materially reducing the precariousness of a livelihood.

NAVIGATION

The trends in western Canada have been away from navigation towards other forms of transport. During the earlier days of settlement the rivers and lakes afforded the easiest means of covering the long distances concerned. As settlement increased and the need for continuous and dependable systems of transport became more pressing, railway and highway transport have superseded navigation. The long winter seasons, during which inland navigation has been at a standstill have placed this form of transportation at a disadvantage in northern climates.

Long after navigation had ceased to be important in the agricultural areas of western Canada, the numerous rivers of the north continued to provide the easiest routes into the more remote regions. Many of these rivers were either small or were so rough and turbulent as to be suitable only for canoes and other small craft, and the navigable reaches were so short as to necessitate frequent portages or trans-shipment. The courses of the rivers frequently made it necessary to follow long circuitous routes in order to reach any desired destination. All of these factors had combined to make the navigation of northern rivers so expensive as to offer a lucrative field for what heretofore had been consid-

ered the most costly method of carriage, namely, aerial transport.

The development of mining and other industries in the northern areas has necessitated the movement of large quantities of heavy freight into these regions. To meet this need a newer form of transport has been devised. Tractor trains carrying almost one hundred tons to the load now move the heavier freight over carefully located winter roads which take full advantage of whatever lakes and rivers are available.

Both of these newer forms of transport are closely associated with water. The open water surfaces of lakes and rivers form the only available landing fields for aeroplanes during the summer seasons. After a brief freeze-up period these same surfaces provide admirable landing fields for ski-equipped aeroplanes. The myriad lakes and rivers of the north are so scattered as to bring almost the entire area within easy access of suitable winter or summer landing fields; making the entire north easily accessible by air and "northern" flying probably the safest and most reliable of any.

The greater proportion of water borne freight in Manitoba is carried on Lake Winnipeg and the lower reaches of the Red River. Over this route freight is carried without trans-shipment from Winnipeg three hundred miles northward to Norway House and thence distributed by other transport methods to a wide range of territory. Various industries such as lumbering and fishing make important uses of this route. Traffic on Lakes Manitoba and Winnipegosis is also chiefly dependent upon these industries.

Navigation on numerous smaller lakes and rivers, while limited to comparatively short distances, remains extremely important to individual communities and industries. Large areas east and west of

The Pas depend upon navigation on the Saskatchewan River for communication with the railway at that point. A large proportion of the freight into the Central Manitoba mining area is carried down Lake Winnipeg to the Wanipigow River and thence by road and river to Long Lake. Various communities situated along larger lakes use trans-lake navigation to connect with nearby roads and railways.

The place of navigation in any comprehensive scheme of water conservation and use is given special significance by the fact that under the terms of the British North America Act the control of navigation was placed under the jurisdiction of the Federal Government. The fact that this one aspect of water resources remains outside the scope of any provincial authority restricts the extent to which purely provincial agencies may deal with navigable rivers and lakes. Any policies or plans which look toward the more complete protection and use of water resources must, in so far as they affect navigation, secure the approval of the appropriate federal authority before becoming operative.

INDUSTRIAL

The industrial uses of water in Manitoba may be classified into three broad groups. The first group includes those uses which, in general, are associated with the mining and paper making industries. The second group of industrial uses includes those usually associated with large towns or cities where, due to the urgency of other uses, adequate water supplies are likely to be available. The industrial uses comprised within this group, while important, are usually

considered incidental to domestic requirements. The third group includes the uses made by those industries which, for considerations other than water supply, might advantageously be established in smaller rural communities. Among the more important industries, besides railways, which may be included within this group are packing plants, creameries, canneries, sugar refineries and such others as may be associated with the processing of agricultural products.

Satisfactory sources of water for industrial purposes, in common with those for most other uses, must be such as to supply the necessary amount of water at all times and the quality of the water must be up to certain standards. The standards of quality required vary from industry to industry. In many industries hardness or the amount of mineral salts in solution may be the chief disadvantage associated with prospective sources of water supply. The industries in which this aspect is particularly important are those which require water either for steam making or in the capacity of a solvent. In the former case the mineral salts are precipitated on the interior surfaces of steam generating plants and cause general deterioration of the equipment, reduced efficiencies and generally increased operation and maintenance costs. In other industries such as laundering, dyeing, soap making and various types of refining, where water is used chiefly for its capacity to dissolve substances, the amounts which can be so dissolved may be definitely limited by the character and amount of mineral salts already in solution. In other instances the substances to be dissolved may form undesirable chemical or physical combinations with the salts previously in solution, resulting either in waste of materials or the formation of undesirable precipitates.

Certain industries commonly established in larger centres where otherwise satisfactory systems of water supply are available, may set quality standards above those obtaining for the general purposes to which any water supply system may be primarily adapted. While it is physically possible to reduce the hardness of any water, the extent to which softening is economically feasible depends jointly upon the amount and type of salts in solution and the use to which the treated water is to be put. Softening or treatment may range from comparatively inexpensive processes to complete distillation, depending upon the ultimate requirements.

In those industries engaged in manufacturing or processing materials for human consumption the purity of the water used is of particular importance. In some cases the processes involve sufficient heat to sterilize any contaminated water. In other instances, however, this is not the case and particular care is required to assure that the water used for such purposes is fit for human consumption.

In those districts where water supply systems have not been developed for other purposes, the matter of a suitable supply may determine the feasibility, or in any case, the locale of further industrial development.

WASTE DISPOSAL AND POLLUTION OF WATERS

The dissolving and transporting capacities of flowing water have been utilized since earliest times for the disposal of wastes and undesirable materials which have been dumped into streams and carried away by the currents, ultimately, it is hoped, to the ocean. The wastes and refuse that have been added to streams by this practice, while of an almost infinite variety, comprise four main types of substances, namely, (1) inorganic solids such as grit,

sand, glass and metals; (2) organic solids such as plant and animal wastes and parts; (3) chemical solutions such as soap solutions, spent dyes, acids and alkalis and (4) micro-organisms or bacteria.

The effect of the addition of these various types of wastes to any river depends upon the amounts so added, the volume of water carried by the river, and the stream velocity. The greater the volume of water carried by any river the greater is the extent of dilution and the lesser the degree of pollution. Streams with higher velocities, due to their greater carrying capacities will support more material in suspension and hence cause a lesser amount of objectionable wastes to be deposited along their beds than would be the case with sluggish streams. Fast flowing streams have a tendency also to break down suspended material into smaller particles, which, in turn, are more readily held in suspension by flowing water.

The seriousness of water pollution through the careless disposal of wastes naturally increases with population density and the increasing demands for satisfactory water supplies. While in earlier times it may have been that streams and lakes could be polluted with comparative impunity because the ground water supplies were ample for the needs of the times, increasing uses have, in many cases, exhausted or depleted these sources and made it necessary to use and protect those supplies which had been so little cared for. As communities grew larger and population more dense, waste disposal came to affect not only the streams but lakes, ponds and ground water supplies.

Improper location of wells and waste disposal areas with respect to one another has led to serious pollution of innumerable sources of water supply. Deep wells have been polluted by surface

drainage from contaminated wastes to the well shafts and thence into the wells. Shallow wells may be polluted in the same manner or by seepage of liquid wastes or water draining through contaminated materials into the shallow water horizons which supply the wells.

This condition may be prevented in the former instance by banking around the well shaft and providing a tight cover or by drainage of the contaminated waters in another direction. In the case of shallow wells, these should be equipped with a tight top and cover and the wastes disposed of at a greater distance from the wells. In very pervious soils this may require the removal of wastes in metal containers and some form of pavement in the drains which are to carry off the contaminated surface waters.

The disposal of wastes along river and stream banks or in runways or ravines from where they readily wash into the rivers presents a constant menace to the health of both humans and livestock. While water for human use is rarely taken from streams without at least sufficient treatment to destroy the micro-organisms or reduce the bacteria, these wastes frequently add tastes and odours to the water which are extremely difficult to eradicate.

One of the foremost principles followed in the protection of human life against many communicable diseases is that water supply must be protected. It is not unreasonable to suppose that this same principle is fundamental to the eradication of many diseases which now infect livestock and there is every reason to believe that waters polluted by livestock wastes are more dangerous to livestock than waters containing wastes of other types - just as waters polluted by human wastes are the most dangerous to human health.

The control of stream pollution where large urban centres are concerned is chiefly a matter of sewage treatment. The suspended organic solids are, to a considerable extent acted upon by the free oxygen which is normally present in water and the amount of free oxygen available has an important relation to the amount of organic materials which the stream can digest. Where the degree of pollution is high there is a heavy demand upon this oxygen, sufficiently heavy in many instances to cause an oxygen deficiency. The amount of free oxygen present in water is thus some measure of the digesting capacity of any stream, whereas the biochemical oxygen demand is an important characteristic of any waste or sewage, and some measure of the load which its disposal would place upon any stream. Several processes are available for the treatment of sewage and the proper choice depends upon the degree of treatment or purification required; the capital cost of plant construction and the annual operating costs that can be incurred.

The disposal into streams of chemical wastes containing spent dyes, waste oils and grease, acids, alkalis, mine or pulp mill wastes may, if sufficiently concentrated, be deleterious to fish life and definitely limit the subsequent uses of the stream for domestic or agricultural purposes.

The difficulties arising from stream pollution by industrial wastes are, however, more economic than technical. The manufacture of by-products from wastes has in many instances been a most satisfactory solution to this problem. Fertilizers are being made from packing plant wastes, activated carbon from the wastes of paper mill.

stock and ferric sulphate from spent dyes.

The extent to which streams can be used for waste disposal depends jointly upon the amounts of various wastes which are added and upon the degree of pollution that can be tolerated. This latter condition depends upon the subsequent uses of the rivers and streams. Without some measure of control, streams may be polluted to such an extent as to become veritable open sewers in which case the scenic, recreational and aesthetic values are completely destroyed, property values reduced and the health of those living in the vicinity prejudiced. Any or all types of stream pollution may definitely interfere with the subsequent use of streams for such purposes as stock watering and public water supply. Even the extent to which a stream may be utilized for waste disposal by one community may be definitely limited by the amount of sewage which had been added by some community situated further upstream.

In probably no other aspect of the broad subject of water use are conflicts more violent than in the matter of waste disposal. What may be medicine to one community literally becomes poison to another. Even in the highly contentious matter of river diversion one community does no worse than deprive another of the use of a stream but in the case of inordinate pollution the lower community may not only be deprived of all uses of a stream but may in addition be harassed with the ever present dangers of epidemic and disease.

There are at present available only very general criteria by which the degree or extent of stream pollution may be defined, and even such criteria as are available usually fail to take into account the all important matter of subsequent use. Partly for this

reason it is extremely difficult for any agency, in the matter of waste disposal, to distinguish definitely between the uses and abuses of streams.

RECREATION AND WILD LIFE

The benefits of adequate recreational facilities such as natural parks and watering places to any community are becoming increasingly recognized. They serve as sources of inspiration and places of rest, recreation and refuge from the disturbing tempo of modern life. They encourage travel and friendly intercourse and a consequent improvement in national and international relationships. Physically, socially and culturally they make for more complete living.

The development and maintenance of summer resort and park facilities provide employment and sources of livelihood to large numbers of people. The influence of these facilities on the tourist industry, and consequently on the balance of trade, is both advantageous and considerable. The advertising value of well developed, carefully preserved and accessible summer resort and tourist attractions are important, particularly to communities that wish to interest prospective settlers and investors. These attractions are not limited to highly developed summer resorts and parks but include the scenic splendours of our hinterland and the natural facilities for sport fishing and hunting of the more remote regions which must be kept unmarred.

The development, stabilization and protection of lakes and marshes toward their more complete utilization for the propagation of fur-bearers and wild-fowl are important aspects of the water use problem. These aspects not only require consideration in the

development of other uses but may in certain instances be primary considerations. Certain large marsh areas, which are unsuited to other purposes may be found to be easily adaptable to the propagation of muskrat, beaver, ducks and wild geese. Experiments in Manitoba and elsewhere have indicated that the wide variations in both the quantity and quality of muskrats pelted are intimately associated with water level variations and are subject to substantial improvement by water level control. Indications are that conditions for the propagation of water-fowl may be similarly improved.

The utilization, where feasible, of whatever natural or artificial summer resort and recreational facilities are available would do much to improve living conditions in the agricultural areas. The maintenance of a prosperous and contented rural population is of fundamental importance to the provincial and national economy. Material prosperity may come to one generation but unless the totality of rural life makes for a contented population those who have accumulated sufficient wealth will migrate and the province will be deprived of the contributions of the most efficient, and our prairie economy remain a pioneer or frontier settlement.

STREAM CONTROL

The detailed purposes and problems of stream control are as varied and numerous as are the characteristics of rivers and the uses of water. In general terms, however, stream control attempts to develop the more productive uses of water and to modify or eliminate its harmful effects. The main objective is to accomplish these results as efficiently and effectively as possible, utilizing

to the full, existing public agencies and the intelligent goodwill of all citizens affected.

The characteristics of any stream have an important relation to the productive uses which may be developed and are equally important in determining the tendencies toward flooding. Probably the most important characteristic is the degree of uniformity or variation in stream flow, usually termed stream regimen. This, as well as other characteristics, depends upon a wide range of natural conditions over the watershed and to a lesser extent upon certain human activities, particularly in farm and forest management.

Stream regimen is essentially the result of an aggregation of natural influences such as precipitation, temperature, lakes and marshes, topography, geology, forest and grass cover and the size of the watershed. The amount, intensity and incidence of precipitation and whether it occurs as rain or snow; the temperatures which determine the amount of evaporation and whether or not run-off occurs immediately after precipitation or only after a subsequent thaw; the amount of storage provided by lakes and marshes, which accumulate water during wet periods and supply water to the stream after precipitation or a spring freshet ceases; the condition of the watershed with respect to both general land slopes and stream bed slopes; the soil types and ground conditions which determine the infiltration and percolation capacities and the amount of precipitation which enters the soil and ground water reservoirs and the extent to which these, in turn, add to stream flow; the extent, density and type of vegetative cover and their combined effects in extending the period of spring thaws, in reducing surface run-off velocities, and in

increasing both soil absorption and transpiration requirements; and, finally, the extent of the watershed in question and whether or not it is large enough to represent a 'general' average of conditions over a wide area or small enough to respond appreciably to purely local conditions - any or all of these may determine the natural regimen of any stream and their relative importance will vary from watershed to watershed.

Largely without any specific intention to do so, certain human activities may alter stream regimen. The clearing of forests may not only increase the run-off from the area in question but the period during which this run-off occurs is likely to be considerably reduced. This applies with particular emphasis to spring thaws and the resulting freshets which are likely to occur during a much shorter period from a cleared than from a forested area with the result that flood flows are intensified and low water flows diminished. Artificial drainage usually seeks to reduce the period normally required for water to find its way from various parts of a watershed into the stream proper. To whatever extent it accomplished this end it tends to add to peak flows and may, in some cases, reduce the amounts added to ground water reservoirs and correspondingly diminish the crucial low water discharges. Certain agricultural practices, in destroying native grasses without substituting an effective vegetative cover may increase the total run-off as well as reduce the period during which run-off takes place. Methods of tillage which ignore natural land slopes may, by smoothing out minor irregularities, increase the effective slope of land to the detriment alike of stream regimen and soil and ground water conditions.

The regimen of the typical prairie stream is extremely irregular even during years of normal precipitation. During drought years this irregularity is further accentuated and main stream channels may carry extremely small flows while the upper tributaries may be dry during considerable proportions of the year. Thus, under the combination of natural and artificial conditions that have prevailed, the water available in prairie streams has been at a minimum during the periods that it has been most urgently required. In practice there has been but slight satisfaction in the knowledge that comparatively large quantities of water may have flowed down the stream a few months previously. From the standpoint of planned water use, however, this knowledge may suggest a partial remedy.

To a large extent the water carried by spring freshets represents waste, - waste of that substance which is most vital to life on the prairies. From the study of hydrologic phenomena reviewed in the preceding pages it would appear that very little or nothing can be done toward increasing the total amount of water available over any considerable period. Indications are, however, that a great deal may be accomplished by a planned soil and water conservation program in making the supplies more continuously available, the fundamental purpose being to extend the period during which run-off occurs.

AGRICULTURAL AND DRAINAGE PRACTICES.

Since the proportion of precipitation absorbed by the soil depends, amongst other things, upon the slope of the land and upon the vegetative and forest cover, it is to a certain extent subject to control. This amount or proportion may frequently be increased



by the use of grasses or other type of vegetative cover and by reducing the effective land slope by tillage methods, contour plowing or terracing. Such practices tend to reduce peak flows, conserve moisture for cropping purposes and may improve ground water conditions and to a certain extent augment low water flow in streams.

Even in comparatively flat lands it is sometimes found that a large proportion of heavy rains or spring run-off may accumulate on lower lying parts of the area. Under these circumstances the lower lands have been either completely inundated until late in the season or have been too wet to permit cultivation and cropping. It frequently happens that the soils of these lower lying areas are highly impervious and that a very small proportion of accumulated water enters the soil or ground water reservoir and an extremely large percentage is lost through evaporation. The common remedy sought for this condition has involved the drainage of this excess water through artificial channels or ditches to natural stream channels. This practice has undoubtedly been responsible for bringing large acreages of fertile lands into production and to that extent has been of advantage to the community.

It does not, however, deal with the whole problem and provides only a partial remedy as the water which normally accumulates to inundate lower lying lands usually represents run-off from some nearby upland. Experiments conducted in the United States and elsewhere indicate that prairie soils can usually be treated and cultivated to retain practically all normal precipitation which falls on them or act as "delayed-delivery works". By soil and water conservation practices which induce soil storage coupled with appropriate land



use methods, both the uplands and lowlands might be used to better advantage and with properly designed drainage channels can be expected to deliver the actual run-off in a somewhat delayed manner instead of a rapid and excessive run-off to the streams at a time when their natural stages were near or at a maximum. In other words, the remedy to chronic land flooding, in many instances, may be found above the flooded areas rather than below them and the nuisance waters put to use rather than wasted and added to already over-burdened streams and rivers.

Stream control, particularly as it relates to our prairie streams, may, therefore, be made quite effective by utilizing the soil as a storage reservoir. Next to the oceans and lakes, the soil represents the greatest natural water storage reservoir available to us. By proper agricultural and forestry practices the non-receptive lands, by appropriate treatment, could be made to absorb a greater part of the rainfall and, acting as catch basins, feed it out over a longer period of time thereby contributing very materially to a more equalized stream flow.

RESERVOIRS

One of the most commonly practised systems of stream control involves the development of artificial storage by the use of reservoirs. The reservoirs are usually constructed by placing control dams across the outlets of lakes, ravines or suitable sections of the river channels. The control dams are then so operated that water stored in the reservoirs during

periods of high flow in the streams is later released to augment the low flows. The degree of control that can be thus effected depends primarily upon the natural regimen and upon the availability of suitable reservoir sites of adequate capacity. Rivers that uniformly carry large amounts of water during certain periods of every year are more suited to this method of control than rivers which are erratic from year to year.

The suitability of any reservoir site for control purposes depends upon its location, capacity, form and cost of development. The location is important with respect to both upstream and downstream conditions. Not only must the reservoirs be so situated that the lower reaches of the river would derive benefit by control but the portion of the watershed above the site must supply a sufficient amount of water for reservoiring purposes. It usually follows that the most dependable sites would be found at considerable distance from the source of a stream whereas, other things being equal, greater use could be made of reservoirs nearer the source. In practice an adequate balance between these opposing criteria is desirable.

The capacity of any reservoir site depends jointly upon its surface area and the average depth to which water may be impounded. The extent to which this capacity may be utilized depends, of course, upon the amount of excess water available for storage purposes which, in turn, depends upon the size of the stream, its natural regimen and the location of the reservoir in relation to the source or sources of the river. A number of reservoirs situated

either along a main stream or its tributaries may be developed where no one site offers the degree of control required. Where the total reservoir capacity is sufficiently large the control period may be extended to smooth out year to year fluctuations as well as to control the seasonal variations.

Where evaporation rates are high the efficiency of any reservoir for control purposes may depend to a large extent upon its form, particularly the area-depth relationships. The evaporation from a free water surface depends upon the temperature of the water and the extent of the evaporating surface. Hence the evaporation losses from deep reservoirs, having smaller surface areas and lower surface temperatures, are uniformly less than from shallow reservoirs in which these conditions, relatively, are reversed.

Seepage losses from reservoirs depend chiefly upon soil types and underground conditions. This aspect of reservoir location is sufficiently important to warrant careful study and examination in the choice of sites. Under most sets of soil and sub-surface conditions seepage losses are much more dependent upon the wetted area than upon the water pressure. For this reason the losses from shallow reservoirs are likely to exceed the losses from deeper reservoirs of corresponding volume.

The feasibility of stream control by the use of storage reservoirs usually depends upon the availability of suitable sites and the costs of development in relation to the benefits likely to accrue. The chief costs usually comprise the expense of procuring the necessary land and of preparing it for use and the costs of

dams and other control structures. In general the former costs depend upon the extent of the area to be flooded, its prior uses, and the value of improvements that require re-location or removal. The costs of structures depend largely upon local conditions but in general they are higher for the development of deep than for shallow reservoirs. Thus, actual land and flooding costs are usually higher for shallow reservoirs while structural costs are usually greater for deep reservoirs. In practice where there is a choice of sites the final selection should be made only after careful consideration of all relevant data and a careful balancing of the numerous factors which govern efficiency and costs.

Where larger reservoir sites are not available or other circumstances prevent their development it may be feasible to treat the stream channel itself as a series of reservoirs. This is usually accomplished by placing control dams at intervals across the stream channel to impound a part of the normal run-off in a series of long narrow lakes.

A large proportion of the upper tributaries of prairie rivers carry water only during a comparatively short spring period and perhaps for a short time after exceptionally heavy rains. The development of even small reservoirs along these upper tributaries or the treatment of the smaller creeks in the manner outlined above offers the advantage of retaining some water in areas where it may be urgently needed for domestic and stock watering purposes and forms an important part in any soil-water conservation program.

The number and size of reservoir sites suitable for the control of prairie rivers as well as the comparatively small amount of water carried during any one year, all but precludes the

possibility of storing sufficient water to smooth out year to year fluctuations of these streams, particularly through a series of wet or dry years.

The physical characteristics of the stream valleys and normal run-off available in the streams of the southern portion of Manitoba preclude the possibilities of any large scale storage reservoirs on an economic basis. Any such possibilities even if designed for dual purposes would be costly and expensive undertakings and of limited use. Elsewhere in Manitoba the numerous lakes and connecting river systems provide excellent opportunities for the control of run-off, and their development as improved breeding grounds and sanctuaries for the fur-bearers and migratory waterfowl, as well as for power, is worthy of careful consideration. Lake Winnipeg is the natural regulating reservoir of numerous rivers and streams having their source far beyond the boundaries of the province and it is this regulating factor that makes the Nelson River one of the greatest potential power producers in the western provinces. Likewise, Lake Winnipegosis and Lake Manitoba are of great potential value as regulating basins and these three large lakes, having a combined surface area of some 13,200 square miles, while of limited value to agricultural development, are the source of a large and important fishing industry ranking second in the production of fresh water fisheries in Canada.

EXCESS WATER

The problems which arise from excess water are of three main classes: (a) those resulting from the periodic accumulation of excess water upon low lying lands which are otherwise suitable for agriculture or other use; (b) those arising from certain lands being

continuously too wet for efficient use in agriculture or forestry; (c) those resulting from periodic flooding by overflow from rivers and streams.

The most common method employed in the treatment of problems of the first class has involved the drainage of the excess water through artificial channels to streams. A large amount of this type of work may be classed as supplementary drainage in so far as it was carried out to reduce the crop hazard on lands which had been in prior use.

One disadvantage which has attached to a large amount of this type of work done to date has arisen from the fact that the works were designed primarily to carry away excess water and have usually been constructed without adequate control. The volumes of water to be removed in some years necessitated the excavation of channels of considerable capacity, which were generally designed to meet maximum conditions. As a result of this practice a large amount of water has probably been wasted during the freshet periods when part of it could later have been used to good advantage either upon the land or as surface supplies. Some part of this difficulty has no doubt arisen from the fact that the need for supplemental drainage became most apparent during exceptionally wet years and both land owners and drainage officials were inclined to give much more consideration to the operation of drainage systems during such years than during dry or even normal periods.

The experience of the recent drought period indicates that the existing drainage systems might render more complete service to the community if they could be more readily adapted to altered conditions. The removal of water quickly from agricultural lands

to the stream channels may be of great benefit during excessively wet years but the same process may be actually harmful during other periods.

In general it would appear that the interests of agriculture on the prairies may be better served by increased effort to prevent such excess run-off from upland areas as is likely to inundate the lower lying lands. Where supplemental drainage is definitely indicated it would frequently be of great value to have control facilities provided by which the amount of water carried and the period of operation could be regulated.

The second group of problems arising out of excess water are usually associated with those areas in which a consistently high water table limits the use of land. The areas affected may be continuously or periodically inundated by shallow marshy ponds or lakes, which, though covered by a stand of grass or hay, may be too wet to support the teams or equipment necessary to harvest it.

Where excessively high water tables occur in forested areas the growth is likely to be of little value, being scrubby and slow maturing. The shallow root systems characteristic of tree growth in these areas make the trees particularly sensitive to slight variations in the water table and the poor anchorage afforded by the combination of soggy top soils and shallow root systems make them easily susceptible to wind damage.

Very little forest drainage has been undertaken in Manitoba but experience elsewhere reveals that very satisfactory results may be expected where this process is carefully undertaken. Particular care is required in this type of drainage so that the water table may be lowered gradually from year to year in order that deep rooting may develop, otherwise if this lowering takes place too



suddenly the water may be carried below the reach of the root systems and the stand killed or weakened.

In the case of marsh or swamp drainage there is a probability that a considerable amount of this work may have been based upon insufficient investigation and study. During the period of rapid land settlement the opinion was widely held that lands not suitable for cultivation and cropping were necessarily waste lands. From an historical view it would appear that reclamation of lands for agriculture and cropping had become a primary or fundamental purpose. As a result of the lessons which this brief history has taught, however, it would appear that a more sound purpose would have been to put all lands to their greatest use even if that use be entirely apart from agriculture.

Under this view the problems arising out of excessively high water tables or marsh and swamp lands may or may not become drainage problems. The solution would depend primarily upon the results of investigations conducted to determine the highest economic utility inherent in such lands. This may be found to be obtainable in any one of several uses. The marsh or swamp lands may reach their optimum use as natural hay lands, as partially improved lands, as reclaimed agricultural lands, as waterfowl preserves or refuges, as natural habitats for fur bearers, or under directed development or use for any or several of these purposes. It is obvious that the actual works required to increase the productivity of lands for any of these areas may require complete drainage, drainage during a part of the season or through some seasons, water level stabilization or flooding to additional depths.



The flooding of lands or other property by the overflow of streams has two distinct sets of causes: (a) those which combine to produce excessive run-off, and (b) those which combine to restrict or limit stream discharge capacity. Out of these two sets of contributing causes there arise two lines along which remedial action may be attempted. One seeks to reduce the amount or intensity of run-off while the other seeks to increase the carrying capacity of stream channels.

The amount and intensity of run-off is largely dependent upon climatological and meteorological conditions and upon the physical condition of any watershed. Figure No.1 shows graphically the combination of climatological and meteorological conditions which preceded and are thought largely to have caused flooding of the valley of the Assiniboine River in the spring of 1922. It will be noted that there were exceptionally heavy rains during the fall of 1921, the precipitation in September, October and November being over twice the normal. Most of this precipitation occurred before the ground was frozen. The soil surfaces would have been saturated, the infiltration capacity reduced and the sloughs and ponds being filled, would have lost their storage capacity. During the ensuing winter the precipitation which fell on the watershed remained on the surface in the form of snow and the river gauge height fell gradually until the early spring thaw. Coincidentally with high temperatures in April, unusually heavy rains fell over the watershed. These rains fell on land which was effectively sealed against any large amount of infiltration by the combination of frozen and saturated soils. The river rose moderately at Brandon until the minimum temperature



crossed the frost line or until the "night thaws" commenced.

During a brief interval thereafter the river rose steeply to overflow the flats on May 2nd and to reach a gauge height $6\frac{1}{2}$ feet higher by May 4th.

For all practical purposes the climatological and meteorological conditions which cause or intensify stream flooding must be regarded as being beyond the power of man to alter. Flood prevention or flood control must then seek to modify or neutralize other contributing causes of flood damage. The scope of possible preventative or remedial action is thus limited to (a) storing part of the excessive run-off above the stream channels, (b) increasing the discharge capacity of these channels, and (c) restricting the uses to be made of lands which are subject to stream overflow.

The storage of upstream run-off is chiefly a matter of increasing the amount or proportion of precipitation which is absorbed by soils and, wherever feasible, of providing storage by reservoirs. Both of these aspects of water storage have been treated briefly in an earlier section. The principles are much the same whether they be employed in moisture conservation or in flood prevention. The storage of water in reservoirs may involve both the development of artificial reservoirs and the re-allocation to this purpose of natural reservoir sites which may have been put to other uses.

While the underlying principles of water storage for drought alleviation and flood control are essentially similar, the operation of reservoirs for these distinct purposes are by no means compatible. The interests of water conservation would require that reservoirs be maintained at the highest possible level whereas for the purpose of flood control they should be maintained at lower levels. Fortunately, however, in the case of prairie watersheds this divergency of

interest is much more apparent than real. Flood conditions rarely occur except during or shortly after the spring break-up. Reservoirs, if of sufficient capacity and operated to retain a part of this run-off, would serve both to reduce the spring flood hazard (the only severe one) and as sources from which to augment the normal low flows of late summer and fall.

The discharge capacity of any stream depends jointly upon the cross-sectional area of the channel and the velocity of flow. Hence, attempts to control flooding by channel improvements may be directed either toward the increase in cross-section or stream velocity or both.

The cross-section of a stream may be increased by deepening, usually by dredging material from the stream bed; or by widening; or by the construction of levees or dykes. In the case of smaller streams a combination of all three may be undertaken and the dredged or excavated material placed along the tops of the banks to form the levees. In the case of larger streams, however, if levees are used they are usually located some considerable distance on either side of the stream channel. The area between the levees and the channel is called a floodway and has a similar effect to channel widening. Any channel improvements which prevent flooding of the valley floor cause higher river stages both above and below the improved section, and also cause the flood wave or crest to move more rapidly downstream. Both the increased stages and greater flood wave velocity are due to the reduced storage capacity of the valley contingent upon confining the stream to a narrower section.

Stream overflow and flooding may be caused or accentuated by artificial channel obstructions such as dams, bridge piers, abutments and approaches, wharves and the settlement of wastes. Consequently the interests of flood prevention require some measure of control over enterprises which may reduce the size of the stream channel and adversely affect stream discharge capacity. The design of structures which restrict or encroach upon stream channels usually involves careful consideration of their safety during floods and of the effects of floods upon the structures themselves. Consideration of the contributory causes of many disastrous floods leads to the conclusion that in many instances too little attention has been given to the probable effects of such structures upon river behaviour and that design should take cognizance not only of the effect of river behaviour upon the proposed structures but also the effect of the structures upon stream behaviour, particularly in so far as they may accentuate flood conditions.

The velocity with which water flows in any stream channel depends upon the slope of the water surface, the smoothness or regularity of the channel and the hydraulic radius. This factor is an index to the shape of the cross-section, being the ratio of the cross-sectional area of the stream to the wetted perimeter.

The velocity and hence the capacity of any stream may be increased by (a) increasing the slope or rate of fall, (b) making the bed and banks more smooth or clearing of vegetation or other obstructions and irregularities, or (c) altering the form of the channel in such manner that cross-sectional area be increased in relation to the wetted perimeter.

The slope or rate of fall on any reach of a river depends upon the difference in elevation and the distance along the stream channel between the ends of the reach under consideration. Since it is not usually feasible to lower the outlet of a stream, the improvement of stream gradient or slope is usually limited to the removal of rocks or ledges which cause uneven gradients, and to the shortening of stream distances by the excavation of cut-offs across bends. Both of these methods usually cause a lowering of stream stages above the improved sections and increased stream stages below them. For this reason the relief of flood conditions over one reach by these methods may accentuate flood conditions below the improved reach.

The growth of grass and shrubs along stream banks and in the beds of high-water courses increases the resistance to stream flow and may cause siltation and a gradual reduction in the cross-sectional area. In small streams particularly the clearing of vegetation may be one of the most effective methods of increasing stream capacity. In the case of very large rivers, however, the removal of vegetation is not likely to have any very permanent effect.

While the dredging of stream channels is usually undertaken in order to increase the cross-sectional area or to improve the stream gradient or slope, this work is usually so planned as to result in an improved area-perimeter relationship or hydraulic radius. This characteristic of channel form is a foremost consideration in designing artificial channels, auxiliary channels, levees and floodways and reservoir outlets.

EROSION CONTROL

Water is foremost amongst the soil forming agencies and the eroding and transporting capacities of ice and water have been primarily responsible for the deposition of the great proportion of all soils. Tremendous quantities of soil are being carried annually from the higher lands into the river valleys, lakes and out to sea.

From the practical standpoint, soil erosion has four aspects which are chiefly detrimental to stability of land and stream use. They are (a) the erosion or washing away of fertile top soils, (b) the gulying of agricultural lands by water flowing at high velocities down the steeper slopes, (c) the cutting away of river banks and consequent destruction of land, and (d) the deposition of the eroded soil in stream beds, lake bottoms, on valley lands, in reservoirs or such other places as it may be detrimental.

Sedimentation in streams and valleys is a widespread natural process which rarely attracts the attention that its importance deserves until after serious flooding has occurred leaving heavy deposits of sediment spread out over fields or left lying in streets and cellars or to block highways and railways. Running water tends to pick up sediment wherever soil and sub-soil materials are exposed and to drop this load at points further down where the velocities have been greatly reduced on the flatter slopes. The extent to which flowing water will erode soils depends jointly upon the velocity of the water and the cohesion of the soil particles. Instances in which soil erosion has been most severe are usually on cultivated sloping lands where the forest cover or grass cover has been removed or the lands over-grazed. The original top soils disappear and the more and more infertile and coarse sub-soil materials are then washed

into the streams. The character of the sediment being deposited in and along the main streams thus gradually changes for the worse. The natural vegetation, whether trees or grasses, has a tendency to bind the soil particles and also reduces run-off velocities. Cultivation and over-grazing frequently alter this natural balance by destroying the soil cohesion and increasing water velocities, both of which tend to increase soil erosion.

Where cultivation has rendered soil more susceptible to erosion, this tendency can be reduced or controlled only by the control of run-off velocity. This in turn largely depends upon the surface slopes and the type and density of the vegetative cover. Since cultivation reduces this cover during at least part of the season, erosion control in these instances must reduce run-off velocities by reducing the effective land slope. The principle underlying the various methods used or advocated for the control of effective land slopes involves increasing the horizontal distance through which the water is required to flow in passing from one elevation to a lower one. In practice contour ploughing, that is, ploughing shallow furrows across the slope rather than up and down the slope, has been found to be extremely effective in preventing erosion from the gentler slopes. Where the slopes are steeper, listing or terracing has been used to reduce both run-off and erosion.

For steep slopes the land should be withdrawn from cultivation and a grass or tree cover planted to act jointly in the reduction of run-off velocities and as a soil binder. In this manner some use may be made of steeply sloping lands and the lower lands protected from damage by the spreading on them of the eroded materials.

The first part of the document is a letter from the President of the United States to the Congress, dated January 1, 1863. The letter is signed by Abraham Lincoln and is addressed to the Senate and House of Representatives. The letter is a copy of the original, which is in the possession of the Library of Congress. The letter is a copy of the original, which is in the possession of the Library of Congress.

The nature and extent of soil erosion as revealed by surveys conducted in the agricultural areas during the past few years has frequently astounded the investigators by the serious inroads made and the irreparable damage done even in localities from which soil erosion had never been reported. Realization that centuries have been required to build humus, that intimate mixture of vegetable and mineral matter which gives to soils their fertility; that the upper few inches of top soil probably represent the most valuable asset any country could possess; that once the destructive process of soil erosion has destroyed or removed this comparatively thin covering, land is practically useless for agricultural purposes; that the welfare and happiness of large proportions of the rural populations are jeopardized so long as this process continues unchecked, is necessary to a full appreciation that soil erosion in all its aspects is one of the most vital problems to be faced.

The comparative ease with which incipient soil erosion may be checked by a good sod or forest cover, in contrast to the irreparable damage it may cause when uncontrolled, indicates the advisability of careful periodic examination of cultivated lands near the steeper slopes and the immediate application of measures designed to check its advance where the first signs of damage may be found. In the light of the experience that is already at hand it is definitely in the interests of owner and community alike to take such remedial measures as may be found necessary to guard against soil losses and the resultant damages.

Rivers flowing through agricultural lands, particularly where the banks are steep and more especially during periods of high water stages when the velocities are greatly increased, have a tendency to erode their banks.

The cutting away of river banks is not only destructive to adjoining property but the increased sedimentation deposited in the stream channel causes sand or mud bars and decreased channel capacity in various reaches of the streams. Remedial measures to guard against bank erosion particularly on the larger streams are generally costly, depending upon the type of protection required. Where it can be utilized, however, the practice of flattening the slope of the banks and covering these with a good sod cover or with planted willows or other suitable shrubs or trees is generally very effective.

The presence of silt or clay in streams does not necessarily indicate that soil erosion has reached a serious state in the watershed or that an advanced state of erosion control would completely eliminate this condition. Reports from earliest times together with the indisputable evidence of their deltas indicate that certain rivers like the Mississippi, the Saskatchewan, the Red and the Assiniboine carried large amounts of silt in suspension long before there were any appreciable areas under cultivation or before other of the more preventable causes of soil erosion were operative.

CHAPTER V.

WATER POWER

GENERAL CONSIDERATIONS

Since the conditions which cause stream flow, i.e., precipitation, run-off, etc., are not constant, there are usually wide variations in the volumes of water which flow into river systems at different times. Those rivers which are fed from the mountain streams, such as the Saskatchewan, and which are characterized by narrow regular channels, usually carry the inflow quickly away and the stream flow varies between wide extremes. In other river systems, such as the Winnipeg and the Churchill which comprise series of lakes, the volumes carried by the rivers are much more constant, due to the natural regulating capacity of the lakes. Rivers are usually classified according to these aspects as being with or without natural control. Since power demand seldom, if ever, varies with the natural regimen of an uncontrolled river, which reaches its peak generally in the spring and diminishes to meagre proportions during the succeeding seasons, it is the naturally controlled rivers that synchronize more closely with power demand. Natural storage, or conditions conducive to artificial storage, are second only in importance to flow and total fall in determining the feasibility of water power development on any river system. Combinations of natural and artificial storage are most advantageous. In this case the seasonal and yearly regimen of the river is regularized by the natural storage. The artificial control permits or more or less water being released to meet the power demand. The importance of storage for water power purposes is further increased by the yearly or seasonal variation in power demand. Storage may be developed in distant lakes and so regulated

that water reaches the plant during the season when the demand for power is greatest. Under such circumstances it is necessary to estimate in advance what the requirements are likely to be.

As well as the seasonal or yearly variation in power requirements there is usually a sharp daily fluctuation in load. Since it is not economically feasible to store the generated energy from one period to another, it is desirable to have additional reserve power that can be brought into service during the peak hours. This reserve power is usually stored in the form of water above the power station. For this reason a large expanse of water immediately above the power plant is a distinct advantage. Such surplus of immediately available water is known as pondage. Thus, storage is usually applied to reservoirs which may be some distance from a power plant but which may be drawn upon to supplement normal low water flows while pondage applies to smaller quantities of water stored near a power plant for the purpose of adjusting the amount of power generated to the daily or short term fluctuations in demand.

The location of any water power site is frequently the controlling factor in determining the economic feasibility of development. If the site is distant or difficult of access the transportation and transmission costs are likely to be correspondingly high. Since transmission losses increase with the length of line, but decrease with line voltage, it is necessary that long transmission lines carry a high voltage. The higher the voltage to be carried, the higher is the cost of transmission line construction and maintenance. Thus, long transmission lines are not only more costly because of their greater length, but the costs per mile usually exceed the corresponding unit costs for shorter lines.

The major portion of the costs incurred in hydro electric power generation are capital costs or carrying charges and these are continuous, whether or not the system is in use. For this reason water power development, to be economically sound, usually requires a continuous market or a high proportion of "base load" and is not suitable to the supply of an erratic demand. Water power is, therefore, a valuable resource only under certain circumstances which permit of its development. There must be an adequate volume of water flowing continuously in the reach of the river under consideration or the possibility of obtaining this condition by the construction of storage reservoirs and the regulation of the river discharge. Foundation conditions must be suitable to permanent and stable construction. Sufficient fall or head must occur naturally or conditions must be favorable to the artificial concentration of this fall. An assured and continuous market must be available for the energy produced and the site must be within economic transmission distance of this market.

PLANNING FOR POWER DEVELOPMENT

While the data relating to the physical features of the site and the plans for the development and the factors relating to industrial and population trends, markets and possible uses of power may be obtained and analyzed within a comparatively short period, there are no methods available whereby stream flow variations can be reliably estimated except upon the bases of past performance. Intelligent planning for the use of water in any large scale project whether it be water power, irrigation, drainage or water supply, cannot be proceeded with without accurate long term records of stream flow to reveal the important river stages under extreme conditions,

both maximum and minimum. The period of record necessary to include all likely variations is generally accepted as being between twenty and forty years. It is obvious that by no conceivable expenditure of effort or money can twenty to forty years' records be made available in any shorter period of time.

It is equally obvious that any postponement in the collection of this critically important stream flow data must cause a corresponding postponement of the date at which this essential information is made available. Lack of hydrometric records during seasons of particularly low flow (such as have occurred during the recent drought period) are especially unfortunate as extremely low river stages leave no evidence of their occurrence. These extremes can only be determined by measurement during the particular season or season when they are prevalent.

There are three general criteria for determining the economic feasibility of water power development. These are respectively the amount and dependability of the power available, the cost of development and transmission and the extent of the existing or potential markets to be served.

DEVELOPMENT AREAS

In applying these criteria it is convenient first to divide the province roughly into two areas, each with its own distinct physical characteristics. The dividing line between these areas commences at the International Boundary a few miles west of the Lake of the Woods and extends northward and westward to the mouth of the Winnipeg River; thence follows the east shore of Lake

Winnipeg to the north end of the lake, and thence extends westward and northward to the Saskatchewan boundary. That portion of the province lying to the west and south of this line forms part of the Great Central Plain of North America, and consists largely of land suited to agriculture, although generally well wooded except in the southwestern section. The remaining portion, situated to the north and east of the dividing line, forms a part of the great Laurentian Plateau, a region of rocky ridges interspersed with innumerable lakes, swamps and muskegs, containing very little land suitable for agriculture, but supporting a well-developed forest growth on its scanty soil cover.

When we examine that portion of the first of these areas that lies south of the Saskatchewan River basin with a view to ascertaining its resources in the way of water power, we observe, first, that the streams in general follow meandering courses in the bottoms of deep wide valleys, have very flat slopes with only occasional rapids, and have beds and banks consisting mainly of silt, gravel and clay, with very few exposures of outcropping rock. These physical factors in themselves render the development of power sites very costly, involving as they do the construction of expensive dams that must be built on poor foundations to sufficient heights to provide the full heads necessary for the production of power. Added to these adverse conditions is another, the most important of all, which is the low average rate of run-off of these streams, combined with extreme irregularity of flow from season to season and from year to year, and the impossibility of securing artificial regulation of the flow except to a minor degree and at excessive cost. These factors, taken together, result, first, in limiting to very small amounts the depend-

able power that these streams are capable of producing, and, second, in establishing such high costs of production that power from these sources cannot compete with that produced otherwise.

Notwithstanding the general unsuitability of these streams as sources of power, they have in the past been developed at a few places to operate saw-mills and grist-mills, and, in two instances, to generate electricity for municipal use. These developments have long since ceased operation, some having been destroyed by fire or flood, and some having been dismantled and abandoned because of the advent of cheaper power from other sources. For the future it is doubtful whether any of these streams will again be used to produce power, unless special circumstances should warrant the construction of small developments for limited seasonal use.

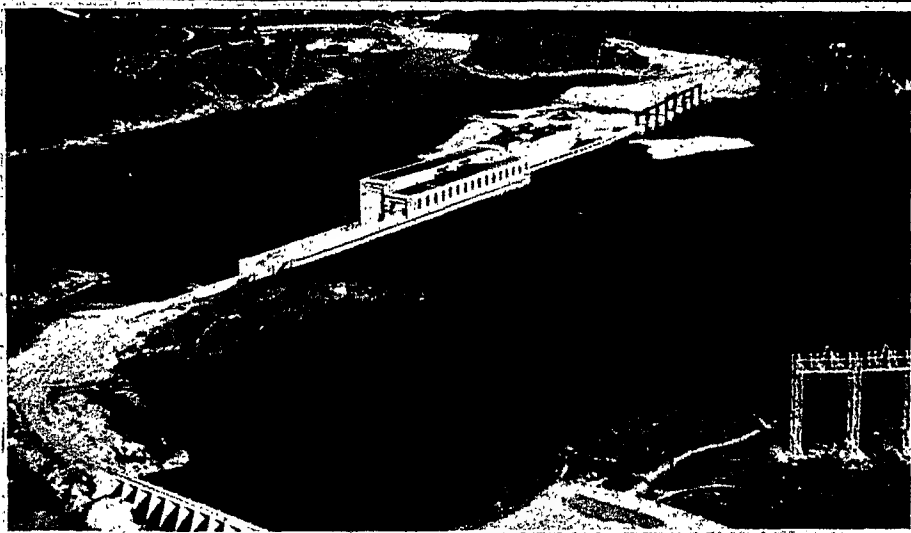
Before considering the streams of the Laurentian region, special attention must be given to the Saskatchewan River, which, although lying within the Great Central Plain area, has certain characteristics that differentiate it from the other streams of this area. This river, like the others, has very wide variations of flow, but unlike the others, has a very substantial run-off and a correspondingly substantial amount of potential power. Preliminary investigations already made indicate that it is feasible to divert this river by way of Lakes Winnipegosis and Manitoba and the Dauphin River to Lake Winnipeg, securing a large degree of regulation of the flow in the two lakes first mentioned and permitting the economic development of the bulk of the potential power.

Turning now to the Laurentian Plateau, we find that the most noticeable physical feature of this area is the rough, hummocky surface exposed in the form of a network of low rocky ridges, with the natural intervening basins occupied by lakes, swamps and muskegs. The streams of this region form the connecting channels between these basins and are characterized by pools of still water alternating with stretches of swift flowing current, broken by numerous rapids and falls. These same rapids and falls, with their beds and banks of rock, provide natural power sites, lending themselves readily to the construction of the necessary dams and other structures. Most important of all, however, is the fact that these streams have fairly high rates of run-off, largely regulated naturally by the many lakes and swamps and susceptible of still further regulation by the construction of relatively inexpensive storage dams.

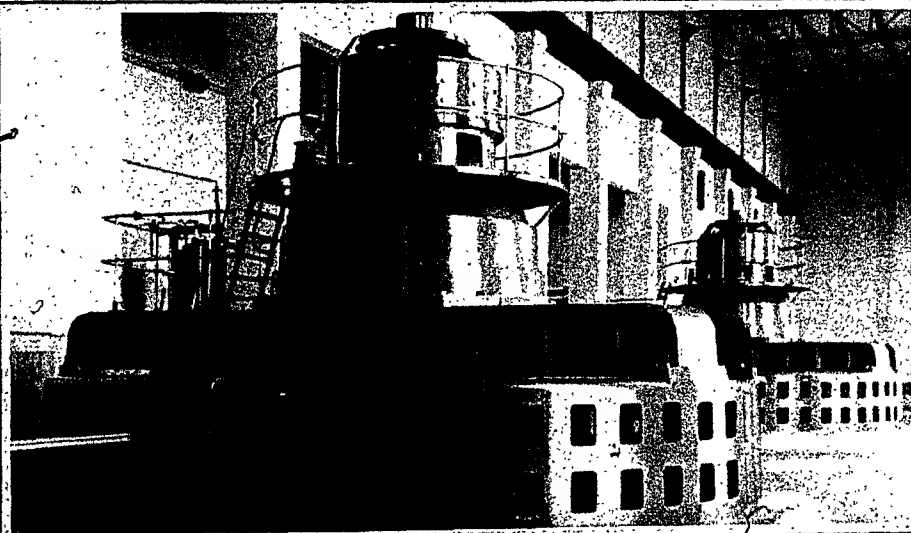
It is in this area that the major water power resources of Manitoba are found. On all the rivers, large or small, are power sites of various potential capacities, ranging from several hundred thousand horse-power down to a few hundred horse-power. Here are found the existing developments that serve our present needs and here must we look for development in the future to supply the progressively increasing demands of our advancing civilization.

DEVELOPED WATER POWER

No definite record is available as to when the first water power development was placed in operation in Manitoba, but it is known that small saw-mills and grist-mills driven by water-wheels were in use about sixty years ago. These and later developments of the same type were all situated on rivers of the prairie region,



SLAVE FALLS POWER DEVELOPMENT.
CITY OF WINNIPEG HYDRO ELECTRIC SYSTEM



GENERATORS. SLAVE FALLS POWER PLANT

near the small settlements of the early days and served a useful purpose during their lifetime. None of these developments are in existence today and it is unlikely that similar developments will again be constructed in Manitoba. The principal reasons for this are, first, that the early settlements have developed into larger communities, with a consequent demand for a larger and more dependable supply of power than these small developments could give them, and, second, that power either produced in local fuel plants or brought in from the hydro electric plants that served the major urban centres, could be obtained in the amounts desired at lower cost.

The first hydro electric development in Manitoba was built on the Little Saskatchewan (or Minnedosa) River in 1900, to supply power to the City of Brandon. This plant had an installation of 1000 horse-power, operating under a head of 26 feet, and was used principally during the summer months as an auxiliary to the steam plant in the city. The plant was abandoned in 1924 and the power house subsequently dismantled, although the dam is still in place. For some years after 1924 the steam plant alone supplied the market in Brandon, but has now been supplanted by hydro electric power supplied through the agency of the Manitoba Power Commission.

A second hydro electric development was built on the Little Saskatchewan River in 1914 to supply power to the Town of Minnedosa, and had an installation of 125 horse-power operating under a head of 19 feet. This plant was sold to the Manitoba Power Commission in 1920 and two semi-Diesel oil engines were installed, these commencing operation in 1921. Minnedosa is now supplied with hydro electric

power from the transmission network of the Manitoba Power Commission and the oil engine installation is maintained as a stand-by.

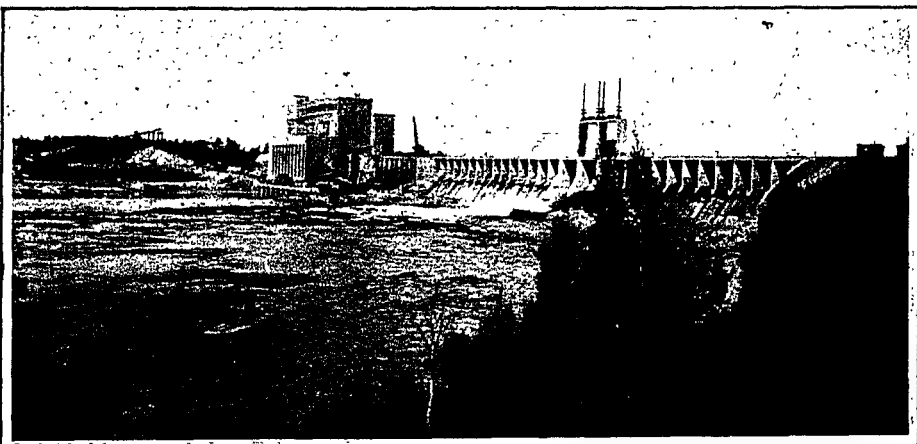
Prior to 1906 the City of Winnipeg depended on steam power for its domestic and industrial use, but in that year the Winnipeg Electric Company completed its development on the Pinawa channel of the Winnipeg River and brought the first hydro electric power to the city. This development is still in operation as a unit of the present Winnipeg Electric Company's system, with an installation of 37,800 horse-power operating under of head of 42 feet.

The second hydro electric development on the Winnipeg River was that of the City of Winnipeg at Pointe du Bois, which first produced power in 1911. This development was added to from time to time, to keep pace with the growing demand for power, until it finally reached its present capacity of 105,000 horse-power in 1926.

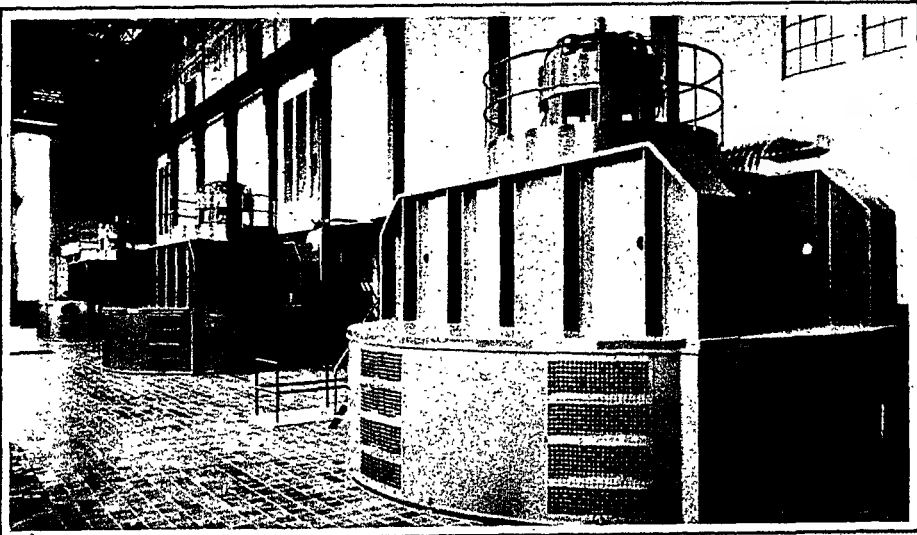
The third development on this river was that of the Manitoba Power Company at Great Falls, which commenced operation in 1923. This development is now a unit of the Winnipeg Electric Company's system and has an installation of 168,000 horse-power.

Two additional developments on the Winnipeg River commenced operation in 1931, these being the Winnipeg Electric Company's plant at Seven Sisters and the city of Winnipeg's plant at Slave Falls. The former of these has at present an installation of 60,000 horse-power, although designed for an ultimate capacity of 225,000 horse-power. The Slave Falls plant is designed for an ultimate capacity of 96,000 horse-power, but has at present 36,000 horse-power installed and an additional unit of 12,000 horse-power under construction.

The latest hydro electric development to be constructed in Manitoba is that of the God's Lake Gold Mines Limited at Kanuchuan,



SEVEN SISTERS DEVELOPMENT
WINNIPEG RIVER



GENERATORS. SEVEN SISTERS POWER
PLANT. WINNIPEG ELECTRIC CO.

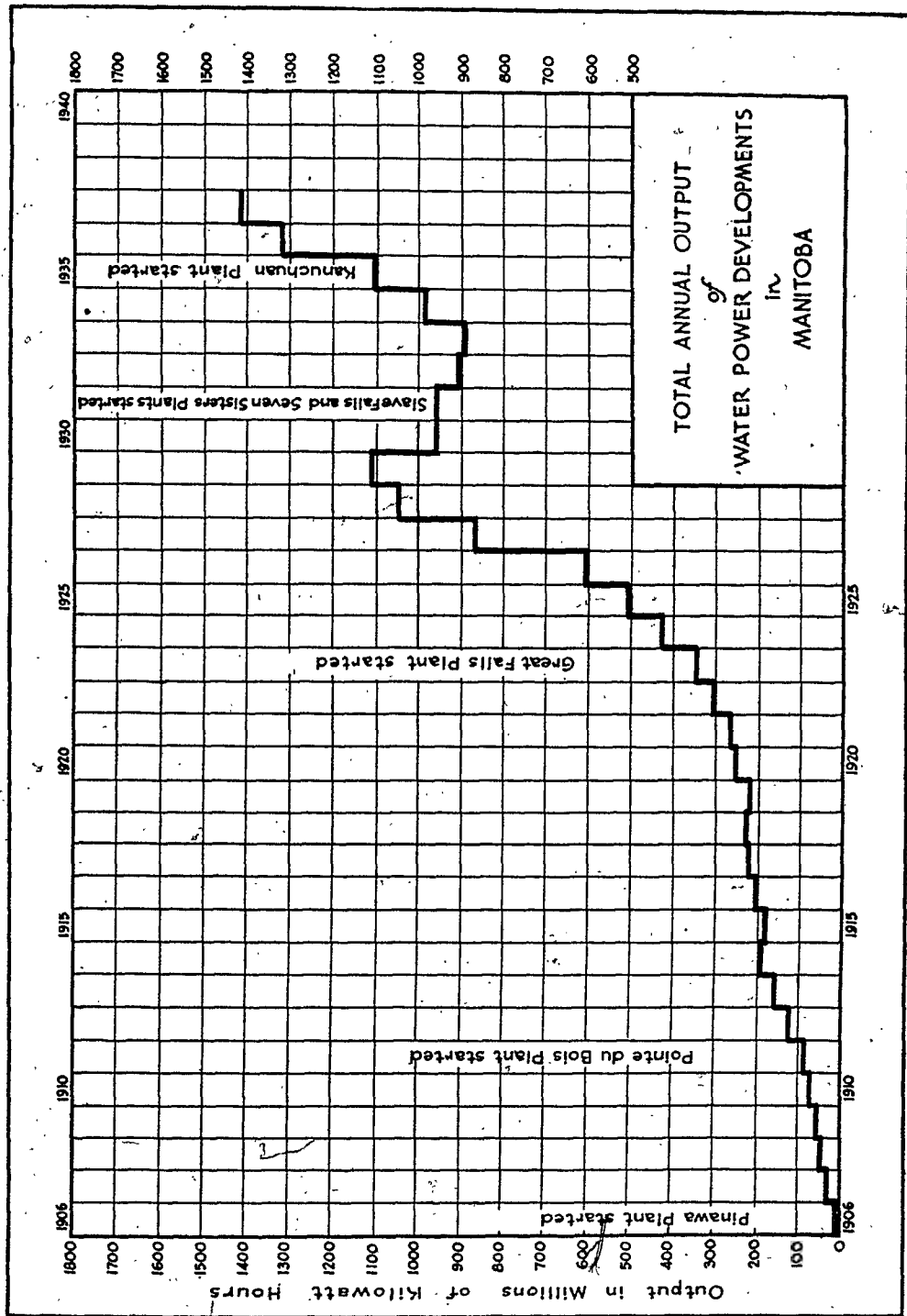


TABLE SHOWING
HYDRO ELECTRIC DEVELOPMENTS IN MANITOBA

<u>Owner</u>	<u>Plant</u>	<u>River</u>	<u>Head in Feet</u>	<u>Horse-Power</u>	
				<u>Dec.31/37</u>	<u>Ultimate</u>
City of Winnipeg	Pointe du Bois	Winnipeg	46	105,000	105,000
City of Winnipeg	Slave Falls	"	30	36,000	96,000
Winnipeg Electric Company	Pinawa	"	42	37,800	-
Winnipeg Electric Company	Seven Sisters	"	66	60,000	225,000
Winnipeg Electric Company	Great Falls	"	56	168,000	168,000
God's Lake Gold Mines Ltd.	Kanuchuan	Island Lake	18	1,900	5,700
Totals				408,700	599,700

UNDEVELOPED WATER POWER

Investigation of the water power resources of Manitoba on a systematic basis was begun in 1911 by the Dominion Government, and was carried on for some years mainly by means of reconnaissance surveys of the more important rivers and by the collection and compilation of records of stream flow. In 1930, on the transfer of the natural resources, the continuation of this investigation became a responsibility of the province, but, owing to the effects of the recent depression and the consequent curtailment of expenditures, comparatively little further work has been done.

Our present knowledge of our water power resources includes information concerning the Winnipeg River in sufficient detail to plan for full development; fairly complete preliminary information concerning the Saskatchewan

River, and the proposed route by which it would be diverted through Lakes Winnipegosis and Manitoba to Lake Winnipeg; preliminary surveys of a number of the smaller rivers in the eastern and northern parts of the province, with scattered measurements of their flow; and partial profiles of the Nelson and Churchill Rivers, with some records of their respective discharges.

By using this information, together with all other pertinent data, it has been possible to arrive at a reasonable estimate of our total known water power resources. These are shown in the following table, first, on the basis of the minimum flow to be expected in the average year, and, second, on the basis of the flow to be expected during at least six months of the average year.

It has been found by experience that when development takes place, the actual installation of machinery may exceed by a considerable amount the estimated six-months' power, and the figures shown may, therefore, be considered conservative.

UNDEVELOPED WATER POWER IN MANITOBA

<u>RIVER</u>	<u>HORSE POWER AT 80% EFFICIENCY</u>	
	<u>Ord.Min.Power</u>	<u>Six-months Power</u>
Berens	12,500	17,900
Big Black	4,400	6,800
Bloodvein	4,000	6,600
Burntwood	8,800	26,400
Churchill	1,500,000	1,800,000
Dauphin	209,600	348,800
Grass	5,000	15,000
Hayes	5,700	17,000
Island Lake	11,000	16,000
Manigotagan	1,200	3,200
Nelson	2,235,000	3,632,000
Pigeon	29,700	39,000
Poplar	3,300	5,000
Wanipigow	400	2,200
Waterhen	32,400	46,300
Winnipeg	100,000	125,000
Total -	4,163,000	6,107,000

NOTE: In the above table, the known undeveloped water powers of the province are grouped for each river under conditions of ordinary minimum flow and six months' flow. Individual sites vary in capacity from 300,000 horse-power down to about 100 horse-power, on the basis of six months' flow.

ADMINISTRATION OF WATER POWER

The water powers of Manitoba are administered by the Minister of Mines and Natural Resources in accordance with the terms of the Water Power Act of 1930 and the regulations in force thereunder. The Act provides that ownership of the water powers shall remain vested in the Crown, but that they may be leased to approved licensees for definite terms of years upon certain specified conditions. Provision is made in the Act for exercising an effective measure of control over not only the developments themselves but also over all the auxiliary works necessary for storing and using the waters and for transmitting power, as well as the construction of the works and the management of the properties.

The regulations define the principles on which the administrative procedure is based and have been drawn up with two main objectives in mind; first, to safeguard the public interest in the water powers, and second, to protect the legitimate rights of those who undertake their development, including the capital invested. To attain these objectives the policy of the department is, in brief, to encourage the development of desirable water power sites and discourage and prevent the development of wasteful and uneconomic projects; to ensure that each site developed shall utilize or provide for the utilization of its maximum available power, and shall fit in with a comprehensive scheme of development of the whole river system; to protect the public from monopolistic control by regulation and periodical revision of rates; and in every way to promote the best use of our power resources to supply the demands made upon them.

An applicant for a water power privilege must file with the Director of Water Power certain plans and other information, including proof of his ability to finance the proposed undertaking. The project is then examined from both the engineering and economic viewpoints and, if it is approved, an interim license is issued. This license is in effect an authorization for construction, which must be proceeded with in accord with certain conditions, including time limits within which stated amounts of power must be ready for use and stated amounts of money expended. The interim license also sets forth the terms and conditions to be incorporated in the final license, which is issued after the satisfactory completion of the development.

The final license, which is the authorization to operate the project, has certain stipulations and conditions, including; the term during which it is to remain in effect, which is limited to a maximum of fifty years; the amount of water that may be diverted and used; the Crown lands that may be occupied for the purpose of the development and its auxiliary works; the annual rentals to be paid for the lands occupied and the water used, the latter being based on the output of power; the area within which the power may be used or sold; and, finally, a provision for recapture by the Crown at any time after a stated term of years, on payment of proper compensation as provided in the regulations.